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Hinchey et al.

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(45) **Date of Patent: Jul. 12, 2011**

(54) **SYSTEMS, METHODS AND APPARATUS FOR PATTERN MATCHING IN PROCEDURE DEVELOPMENT AND VERIFICATION**

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(73) Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1329 days.

(21) Appl. No.: **11/533,837**

(22) Filed: **Sep. 21, 2006**

(65) **Prior Publication Data**

US 2007/0067755 A1 Mar. 22, 2007

Related U.S. Application Data

(63) Continuation-in-part of application No. 11/461,669, filed on Aug. 1, 2006, which is a continuation-in-part of application No. 11/203,590, filed on Aug. 12, 2005, now Pat. No. 7,739,671, which is a continuation-in-part of application No. 10/533,376, filed on Apr. 29, 2005, now Pat. No. 7,484,688.

(51) **Int. Cl.**
G06F 9/44 (2006.01)
G06F 9/45 (2006.01)

(52) **U.S. Cl.** **717/127**; 717/128; 717/131; 717/141

(58) **Field of Classification Search** .... None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,247,651 A *	9/1993	Clarisse	....	703/13
6,898,791 B1 *	5/2005	Chandy et al.	....	719/314

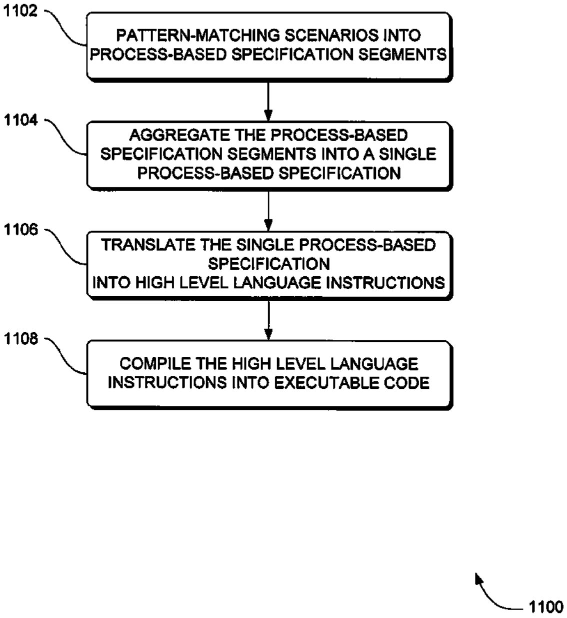
* cited by examiner

Primary Examiner — Chuck O Kendall
(74) *Attorney, Agent, or Firm* — Heather Goo

(57) **ABSTRACT**

Systems, methods and apparatus are provided through which, in some embodiments, a formal specification is pattern-matched from scenarios, the formal specification is analyzed, and flaws in the formal specification are corrected. The systems, methods and apparatus may include pattern-matching an equivalent formal model from an informal specification. Such a model can be analyzed for contradictions, conflicts, use of resources before the resources are available, competition for resources, and so forth. From such a formal model, an implementation can be automatically generated in a variety of notations. The approach can improve the resulting implementation, which, in some embodiments, is provably equivalent to the procedures described at the outset, which in turn can improve confidence that the system reflects the requirements, and in turn reduces system development time and reduces the amount of testing required of a new system. Moreover, in some embodiments, two or more implementations can be "reversed" to appropriate formal models, the models can be combined, and the resulting combination checked for conflicts. Then, the combined, error-free model can be used to generate a new (single) implementation that combines the functionality of the original separate implementations, and may be more likely to be correct.

27 Claims, 25 Drawing Sheets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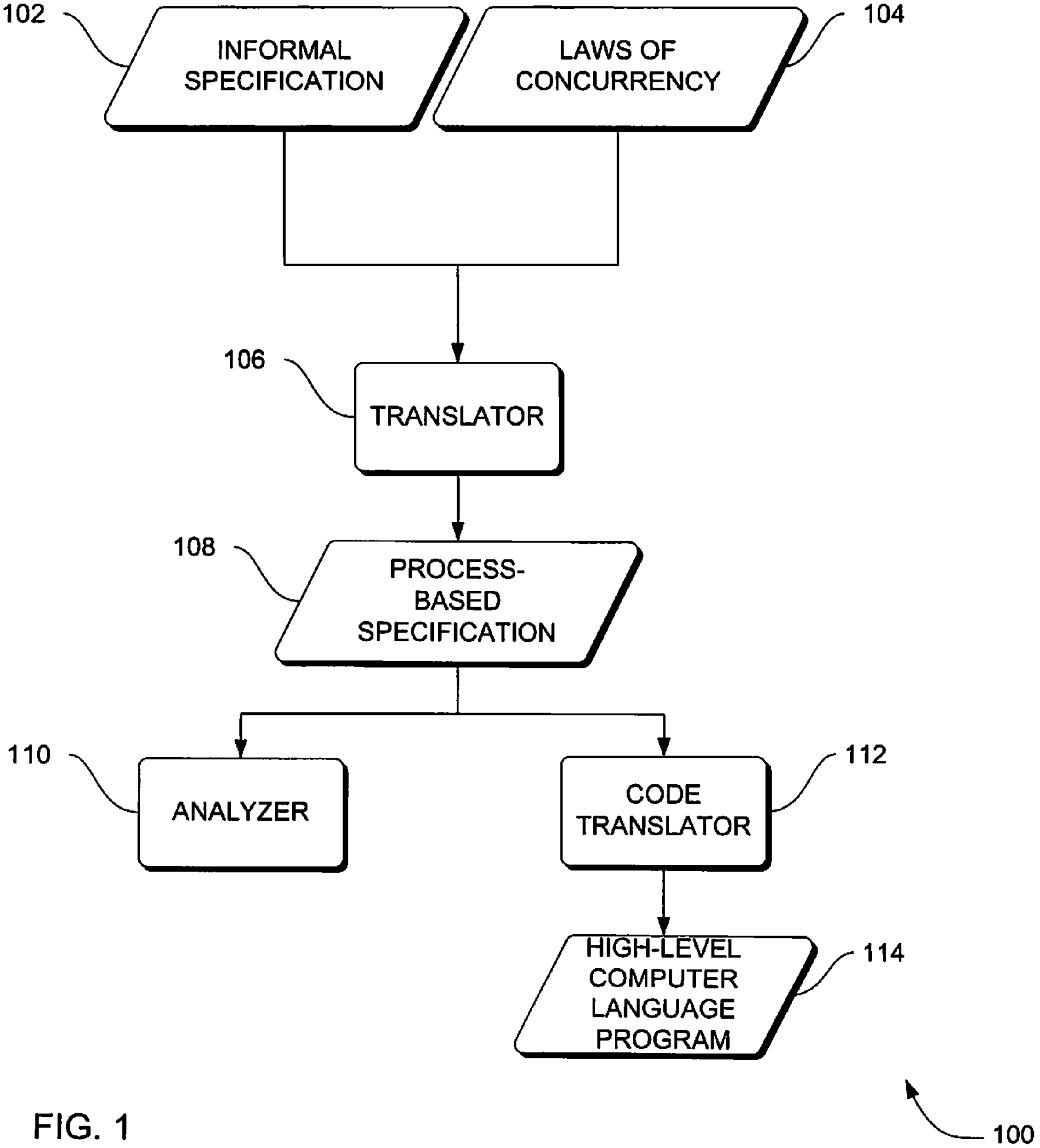
PATTERN-MATCHING SCENARIOS INTO PROCESS-BASED SPECIFICATION SEGMENTS
1104
AGGREGATE THE PROCESS-BASED SPECIFICATION SEGMENTS INTO A SINGLE PROCESS-BASED SPECIFICATION
1106
TRANSLATE THE SINGLE PROCESS-BASED SPECIFICATION INTO HIGH LEVEL LANGUAGE INSTRUCTIONS
1108
COMPILE THE HIGH LEVEL LANGUAGE INSTRUCTIONS INTO EXECUTABLE CODE
1100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104
106
TRANSLATOR
108
PROCESS-BASED SPECIFICATION
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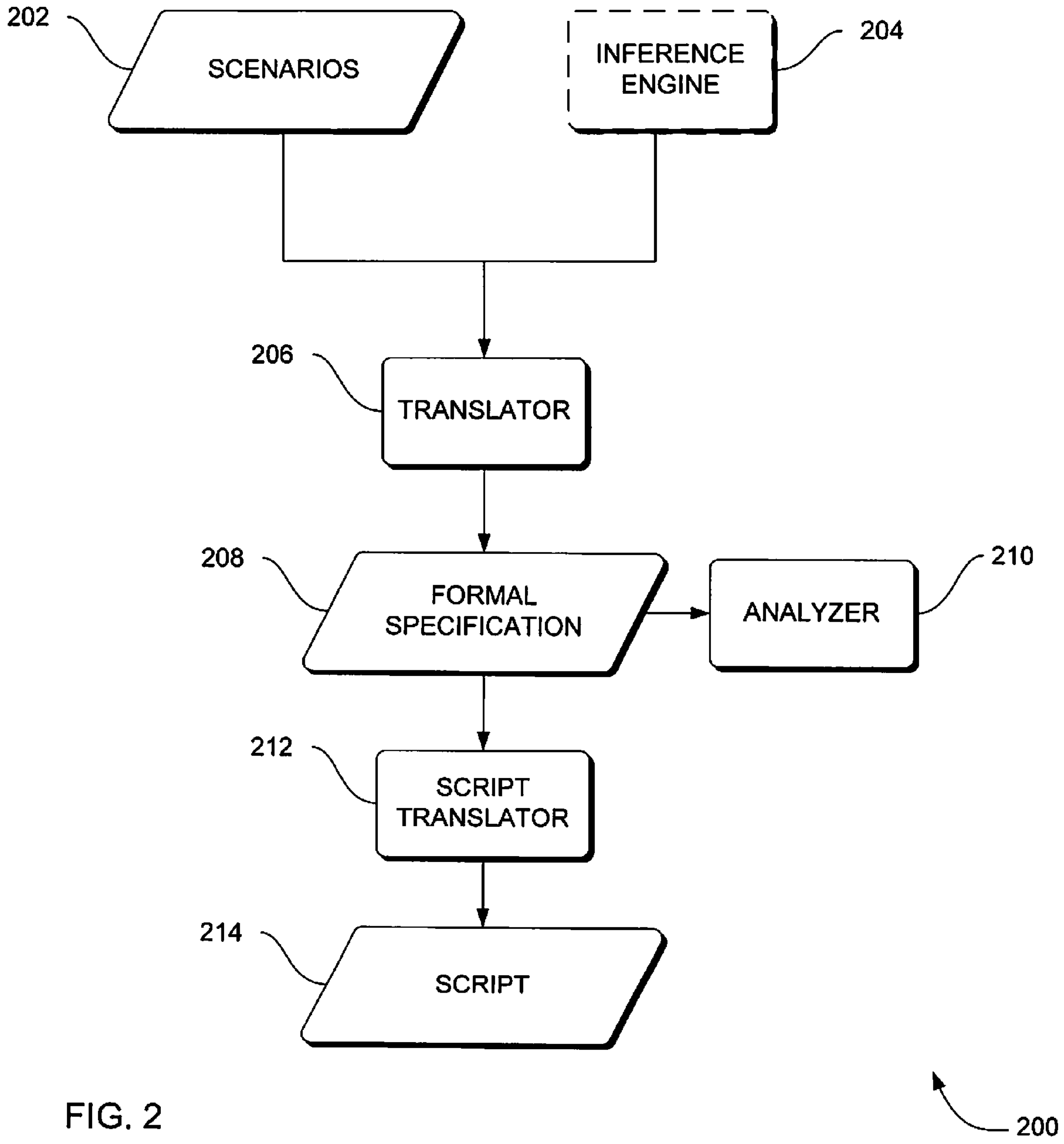
ANALYZER
CODE TRANSLATOR
112
HIGH-LEVEL COMPUTER LANGUAGE PROGRAM
114
100

FIG. 1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SCRIPT
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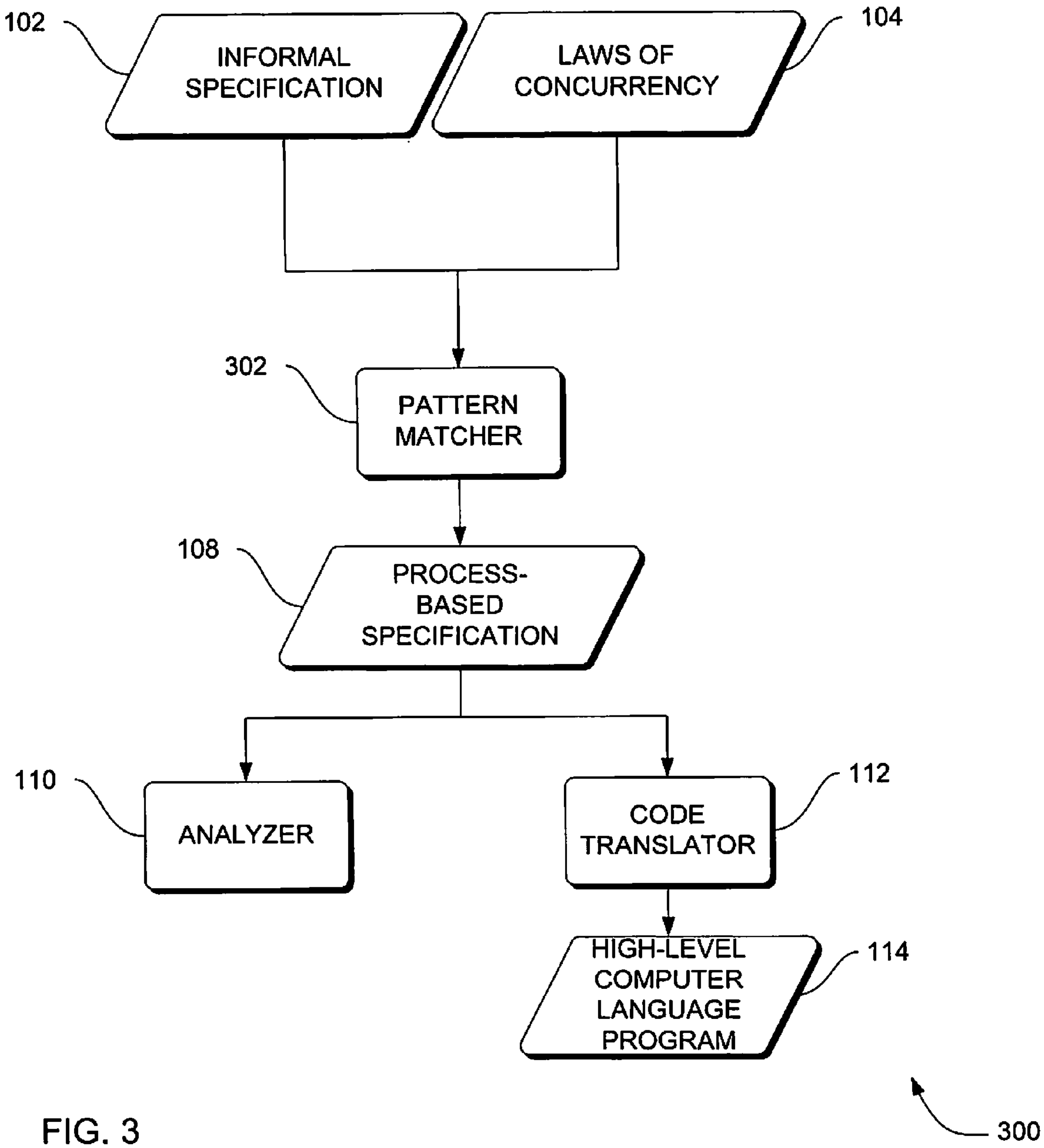
FIG. 2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HIGH-LEVEL COMPUTER LANGUAGE PROGRAM
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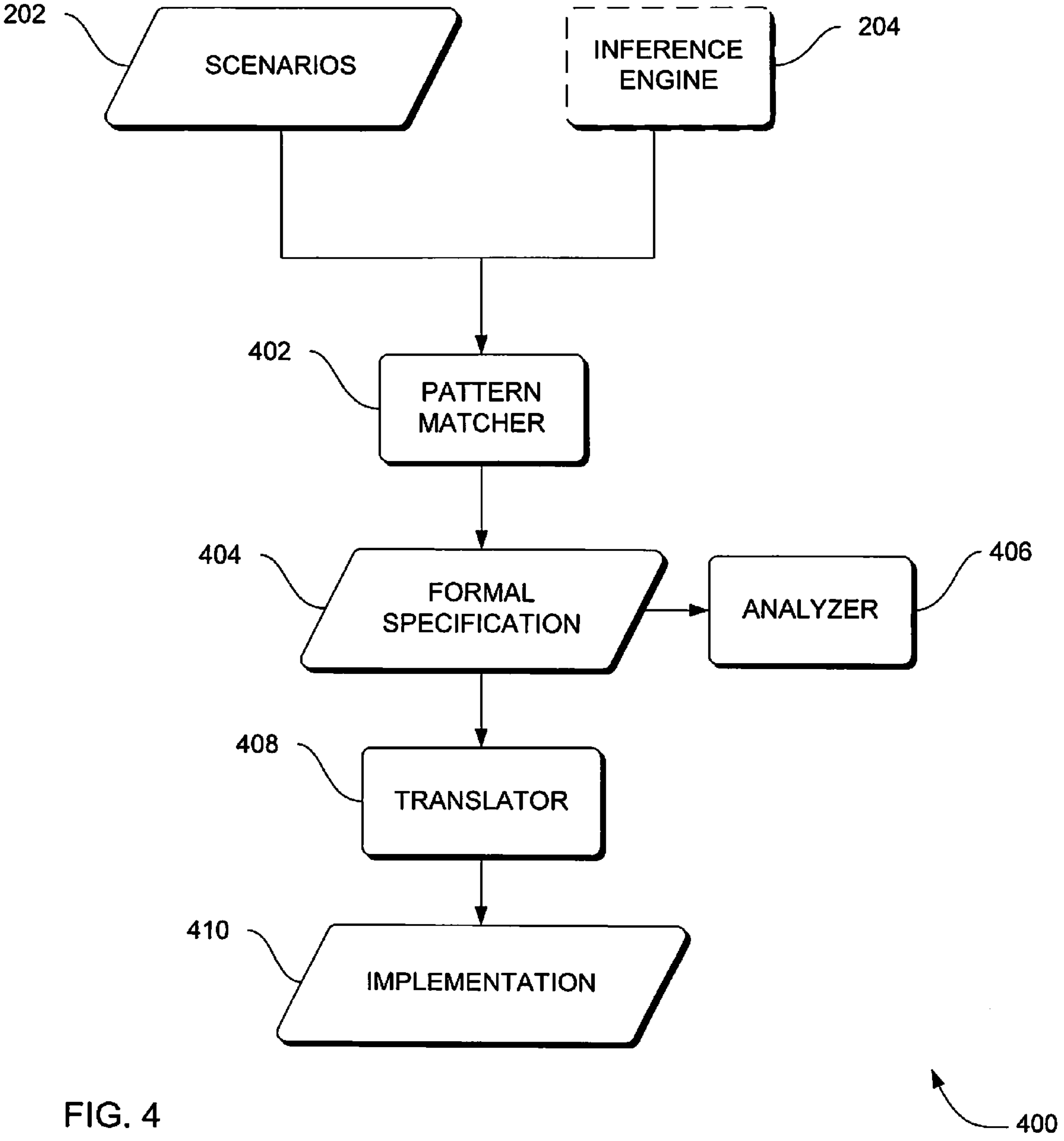
FIG. 3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TRANSLATOR
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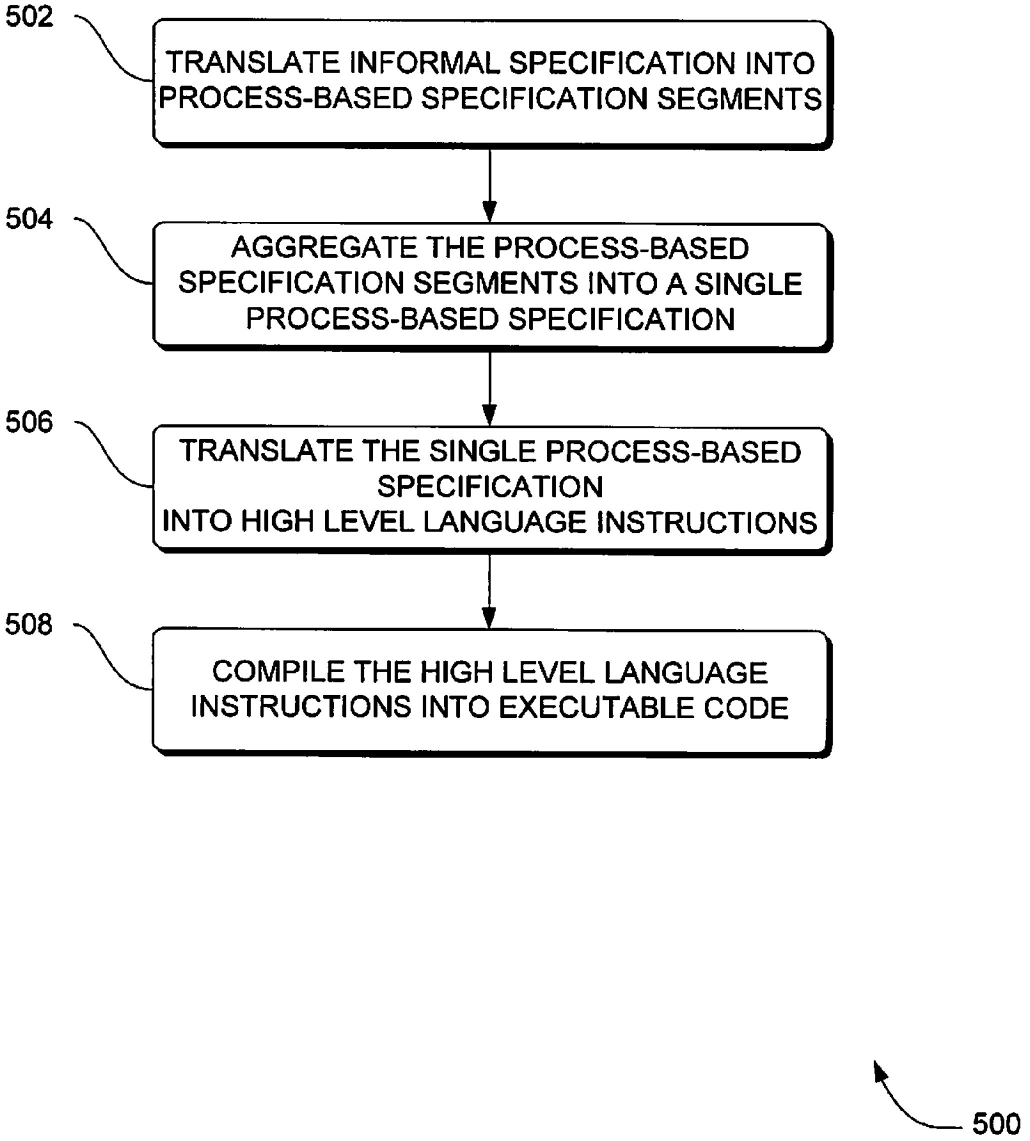
IMPLEMENTATION
400

FIG. 4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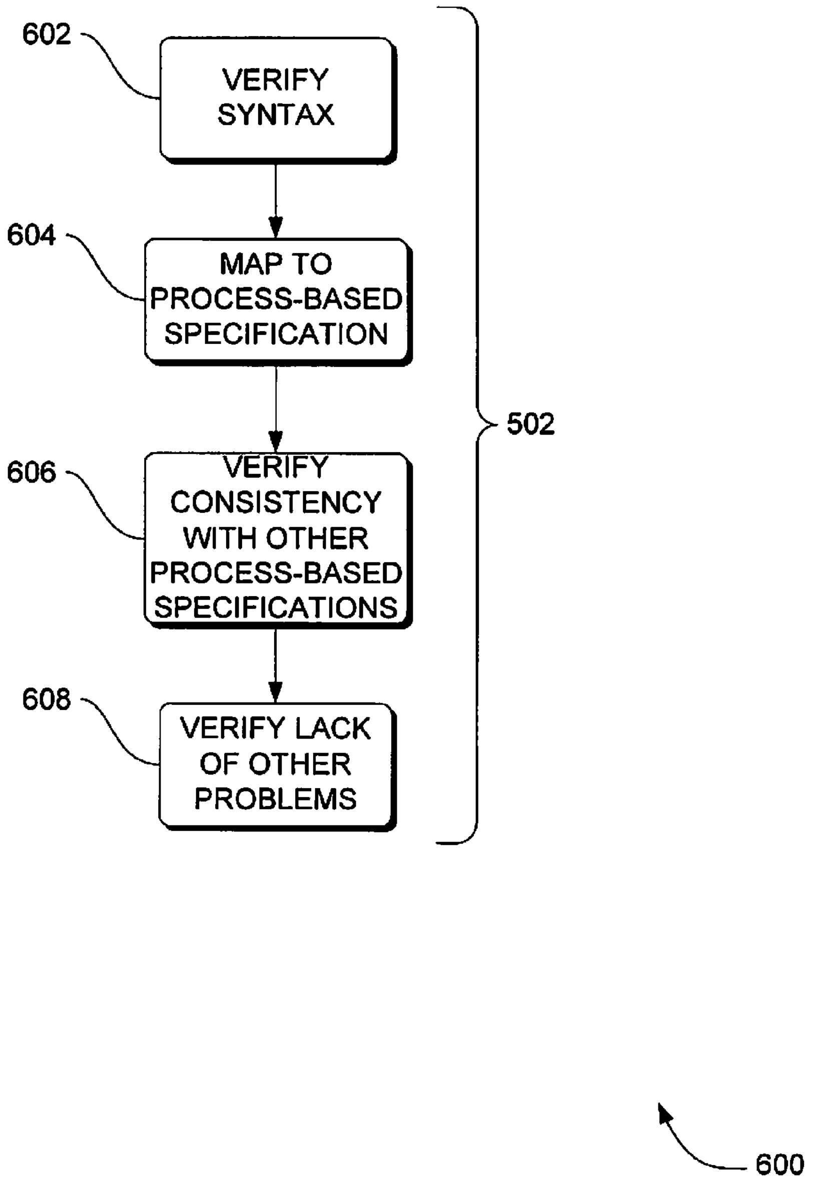
TRANSLATE INFORMAL SPECIFICATION INTO PROCESS-BASED SPECIFICATION SEGMENTS
504
AGGREGATE THE PROCESS-BASED SPECIFICATION SEGMENTS INTO A SINGLE PROCESS-BASED SPECIFICATION
506
TRANSLATE THE SINGLE PROCESS-BASED SPECIFICATION INTO HIGH LEVEL LANGUAGE INSTRUCTIONS
508
COMPILE THE HIGH LEVEL LANGUAGE INSTRUCTIONS INTO EXECUTABLE CODE
500

FIG. 5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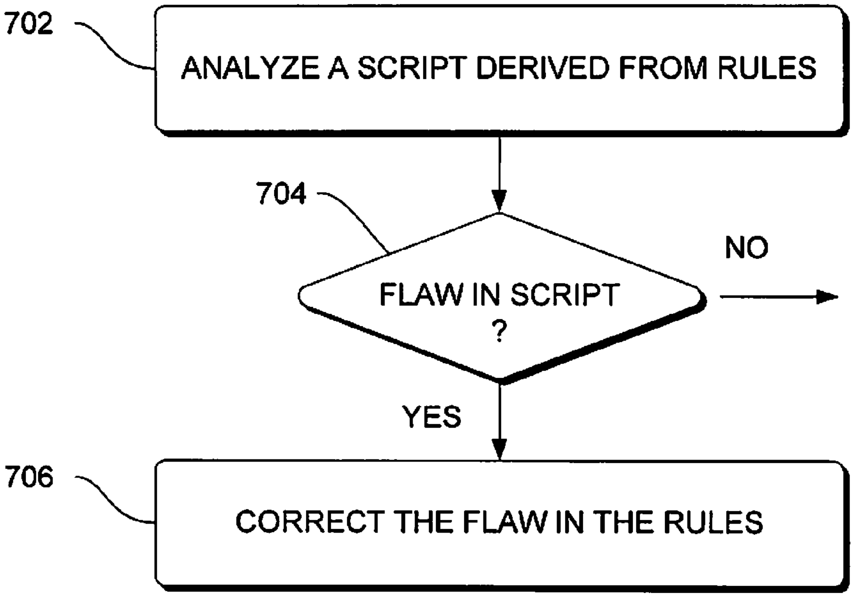
VERIFY SYNTAX
604
MAP TO PROCESS-BASED SPECIFICATION
606
VERIFY CONSISTENCY WITH OTHER PROCESS-BASED SPECIFICATIONS
608
VERIFY LACK OF OTHER PROBLEMS
502
600

FIG. 6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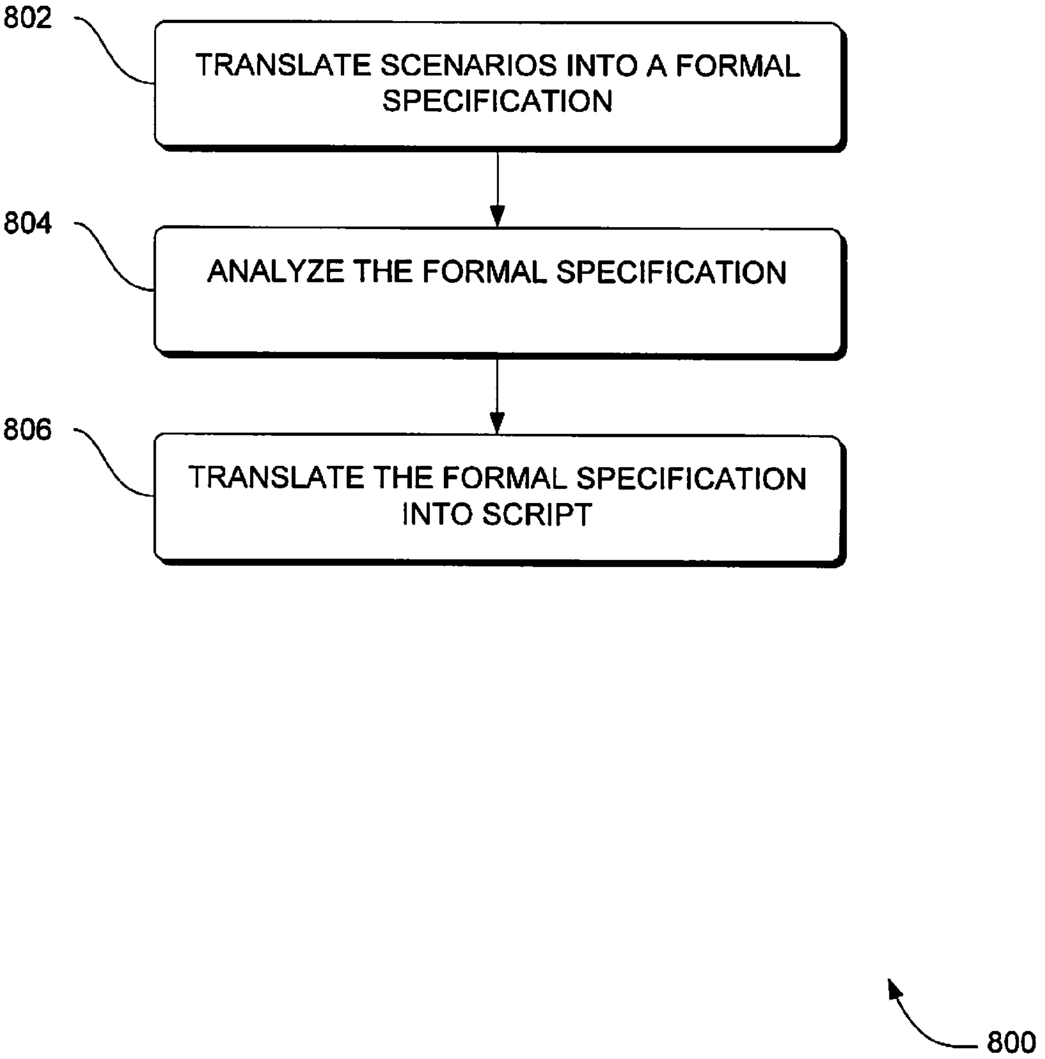
ANALYZE A SCRIPT DERIVED FROM RULES
704
FLAW IN SCRIPT ?
NO
YES
706
CORRECT THE FLAW IN THE RULES

FIG. 7

700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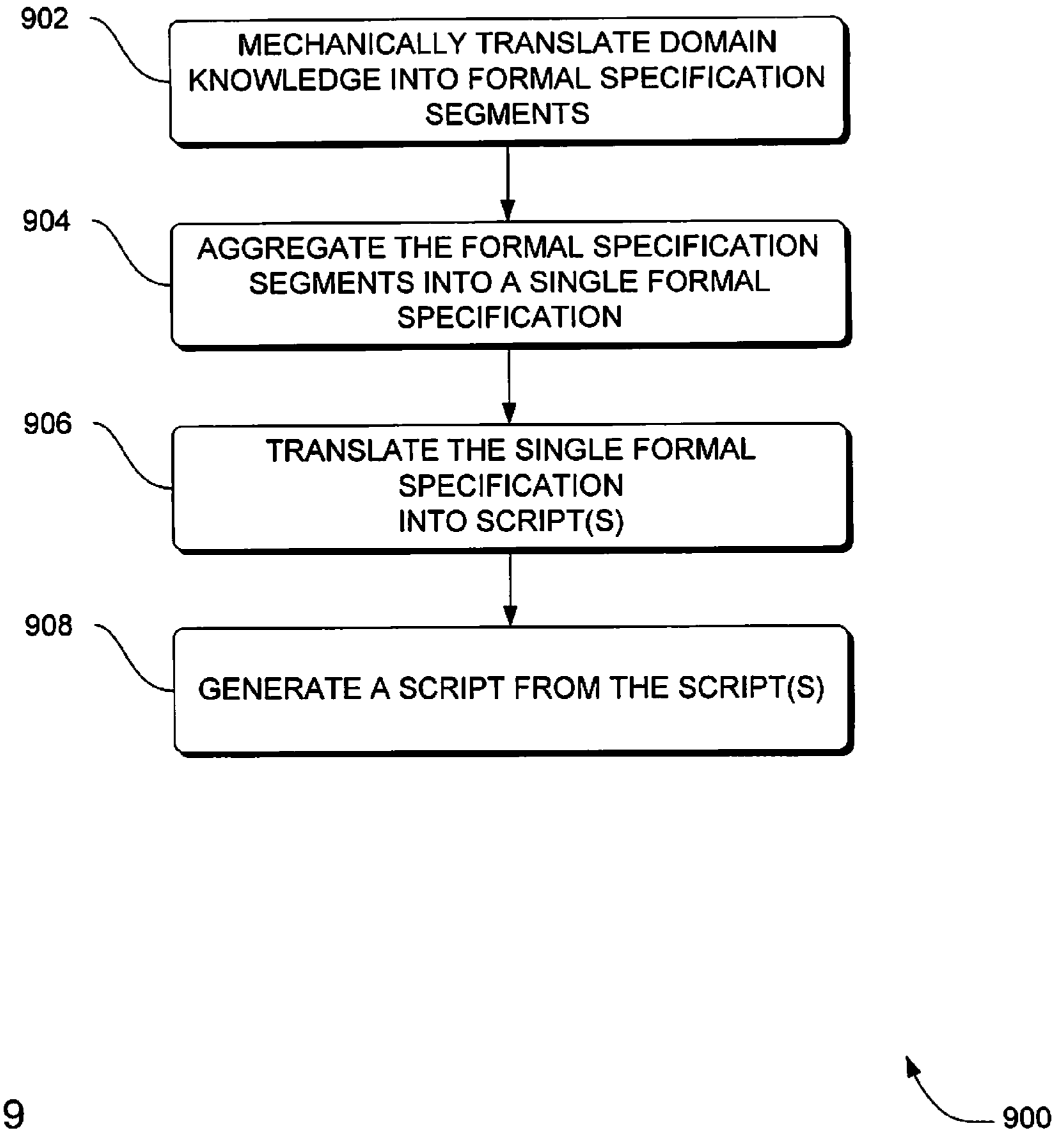
TRANSLATE SCENARIOS INTO A FORMAL SPECIFICATION
804
ANALYZE THE FORMAL SPECIFICATION
806
TRANSLATE THE FORMAL SPECIFICATION INTO SCRIPT
800

FIG. 8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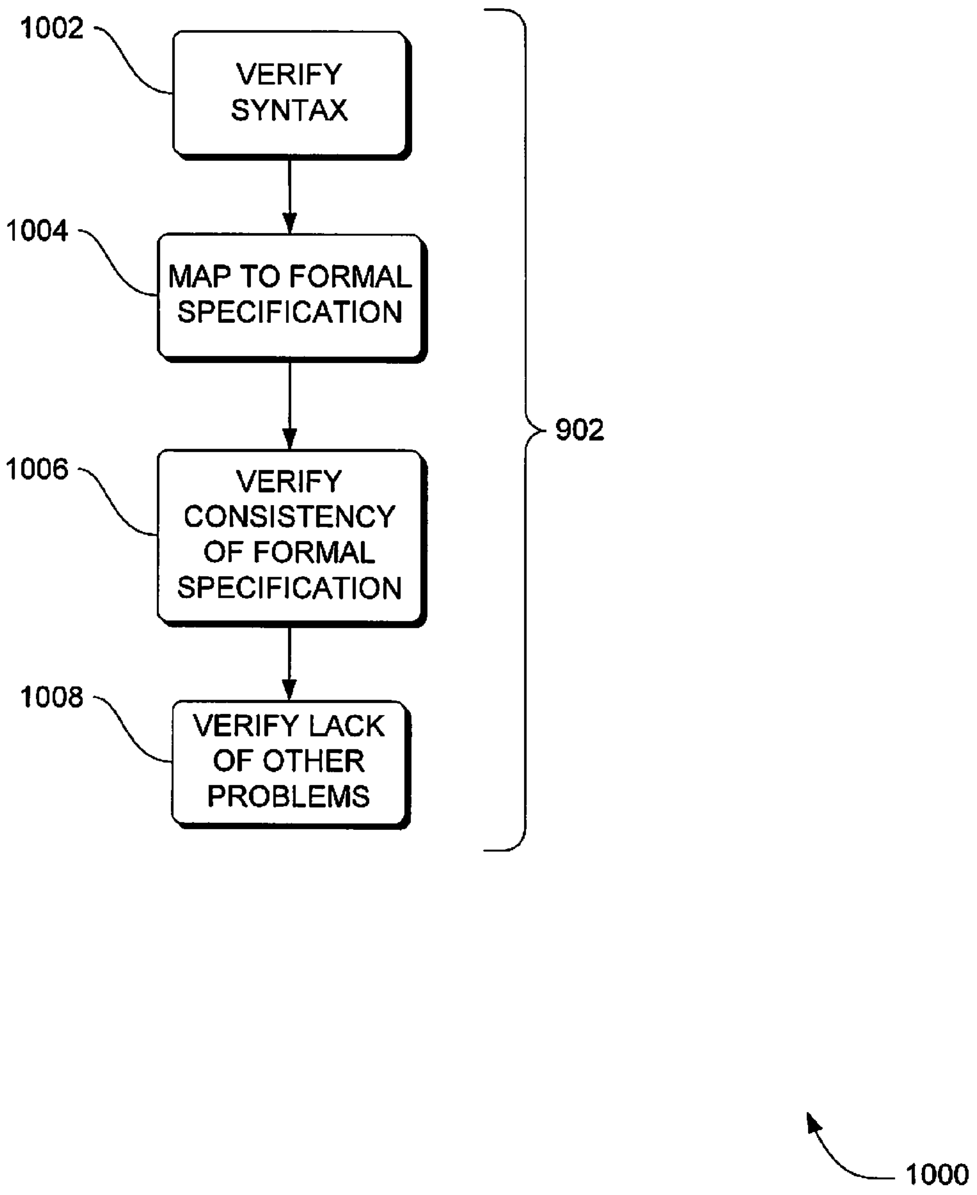
MECHANICALLY TRANSLATE DOMAIN KNOWLEDGE INTO FORMAL SPECIFICATION SEGMENTS
904
AGGREGATE THE FORMAL SPECIFICATION SEGMENTS INTO A SINGLE FORMAL SPECIFICATION
906
TRANSLATE THE SINGLE FORMAL SPECIFICATION INTO SCRIPT(S)
908
GENERATE A SCRIPT FROM THE SCRIPT(S)
900

FIG. 9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VERIFY SYNTAX
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MAP TO FORMAL SPECIFICATION
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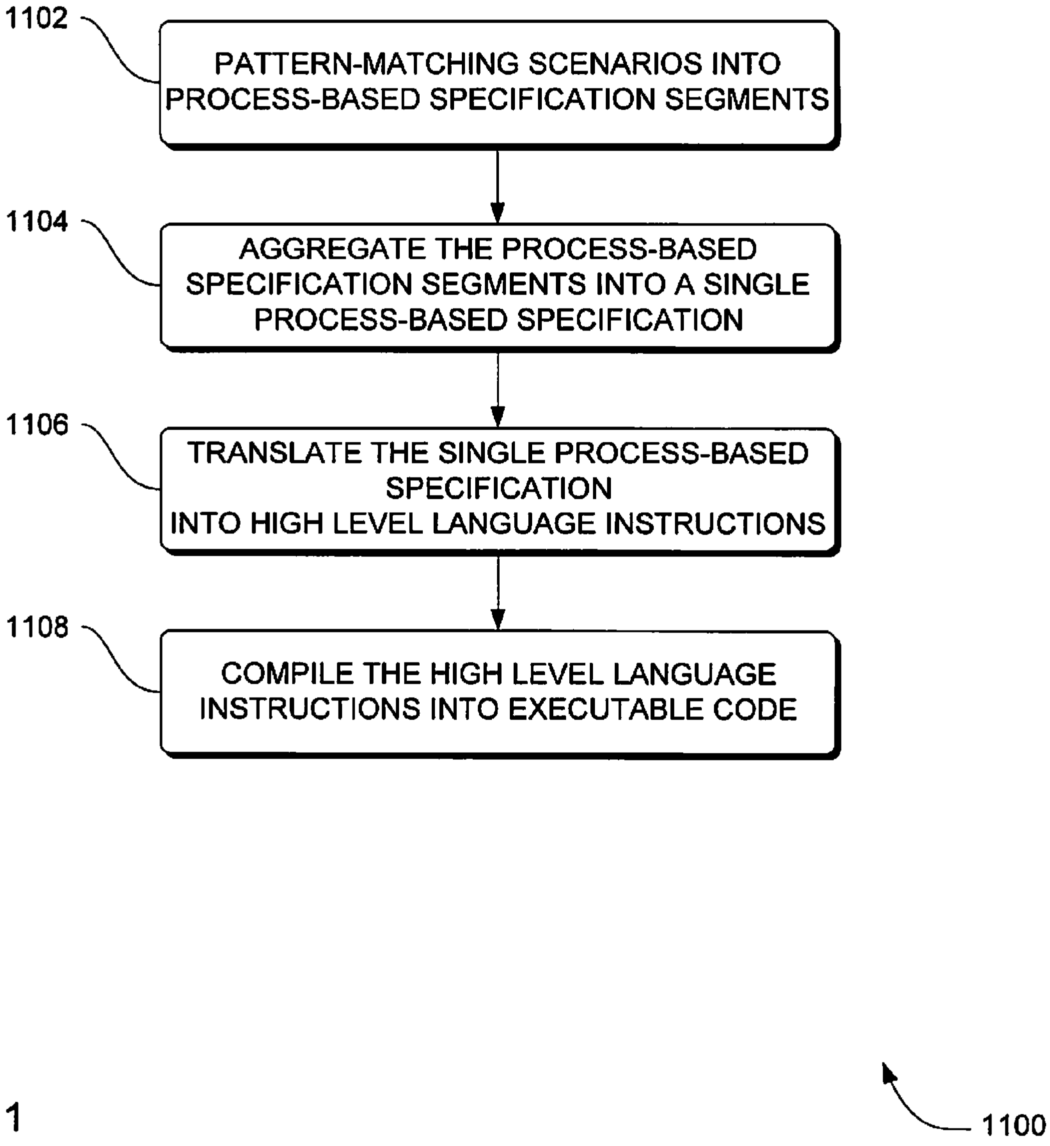
VERIFY CONSISTENCY OF FORMAL SPECIFICATION
1008
VERIFY LACK OF OTHER PROBLEMS
902
1000

FIG. 10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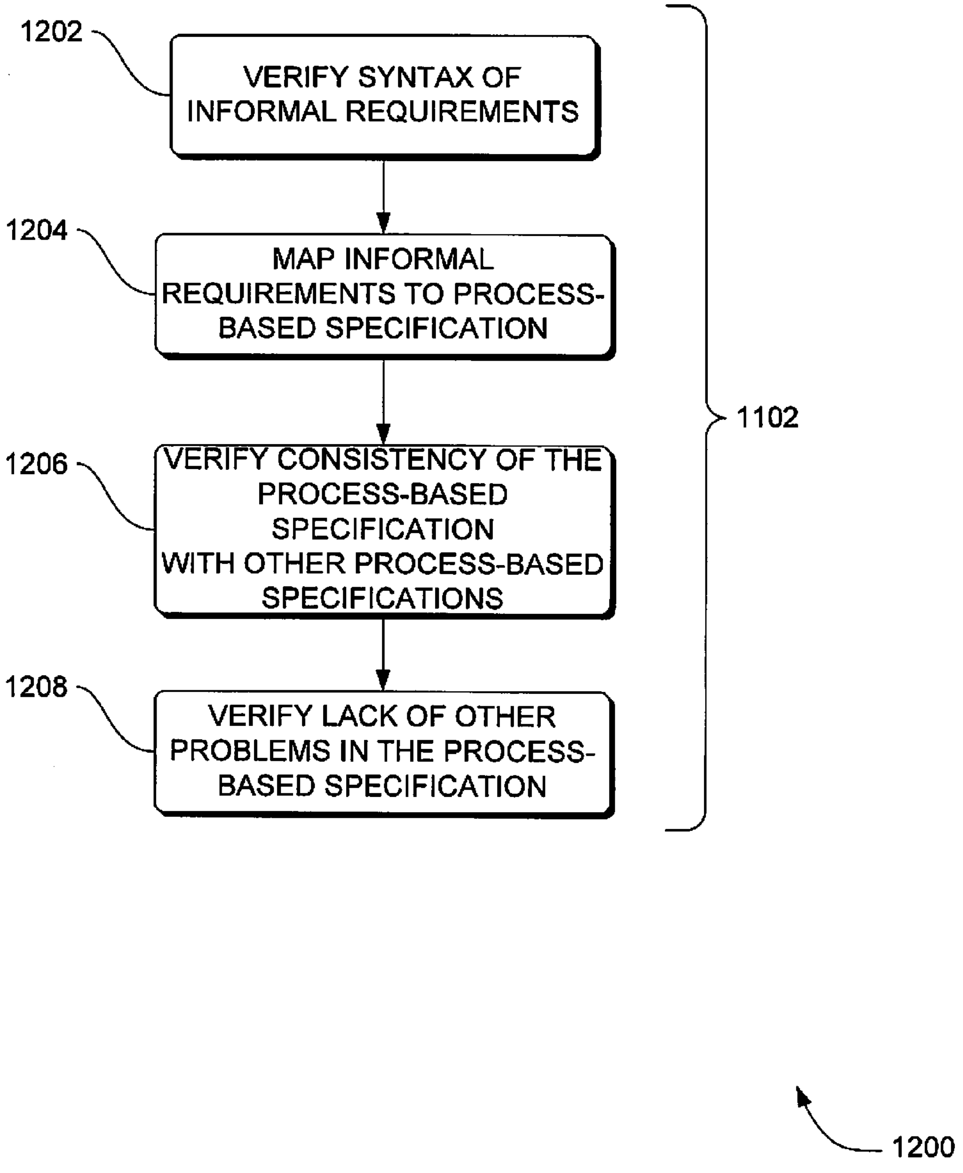
PATTERN-MATCHING SCENARIOS INTO PROCESS-BASED SPECIFICATION SEGMENTS
1104
AGGREGATE THE PROCESS-BASED SPECIFICATION SEGMENTS INTO A SINGLE PROCESS-BASED SPECIFICATION
1106
TRANSLATE THE SINGLE PROCESS-BASED SPECIFICATION INTO HIGH LEVEL LANGUAGE INSTRUCTIONS
1108
COMPILE THE HIGH LEVEL LANGUAGE INSTRUCTIONS INTO EXECUTABLE CODE
1100

FIG. 11


1202
VERIFY SYNTAX OF INFORMAL REQUIREMENTS
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MAP INFORMAL REQUIREMENTS TO PROCESS-BASED SPECIFICATION
1206
VERIFY CONSISTENCY OF THE PROCESS-BASED SPECIFICATION WITH OTHER PROCESS-BASED SPECIFICATIONS
1208
VERIFY LACK OF OTHER PROBLEMS IN THE PROCESS-BASED SPECIFICATION
1102
1200

FIG. 12

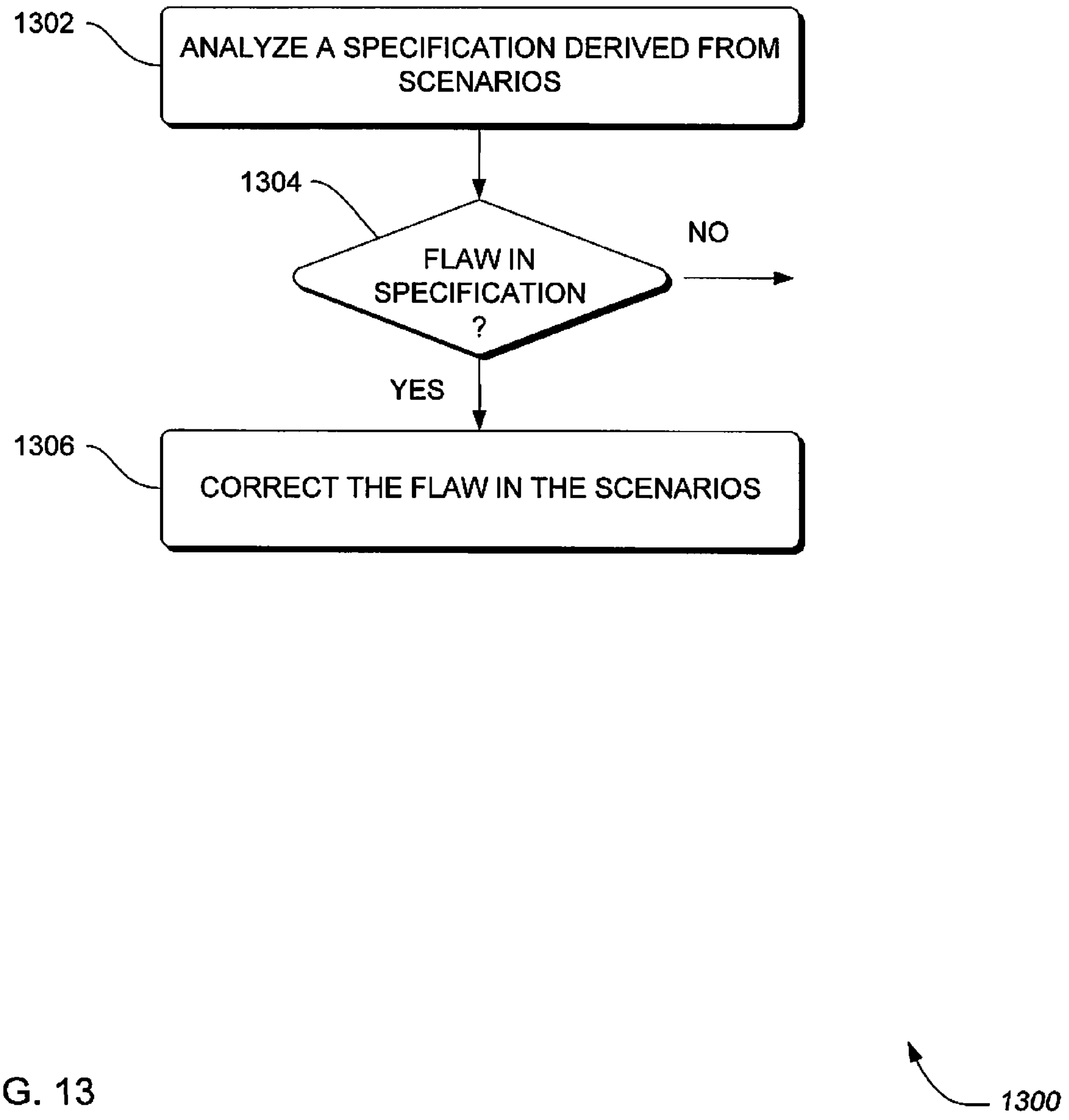

1302
ANALYZE A SPECIFICATION DERIVED FROM SCENARIOS
1304
FLAW IN SPECIFICATION ?
NO
YES
1306
CORRECT THE FLAW IN THE SCENARIOS
1300

FIG. 13

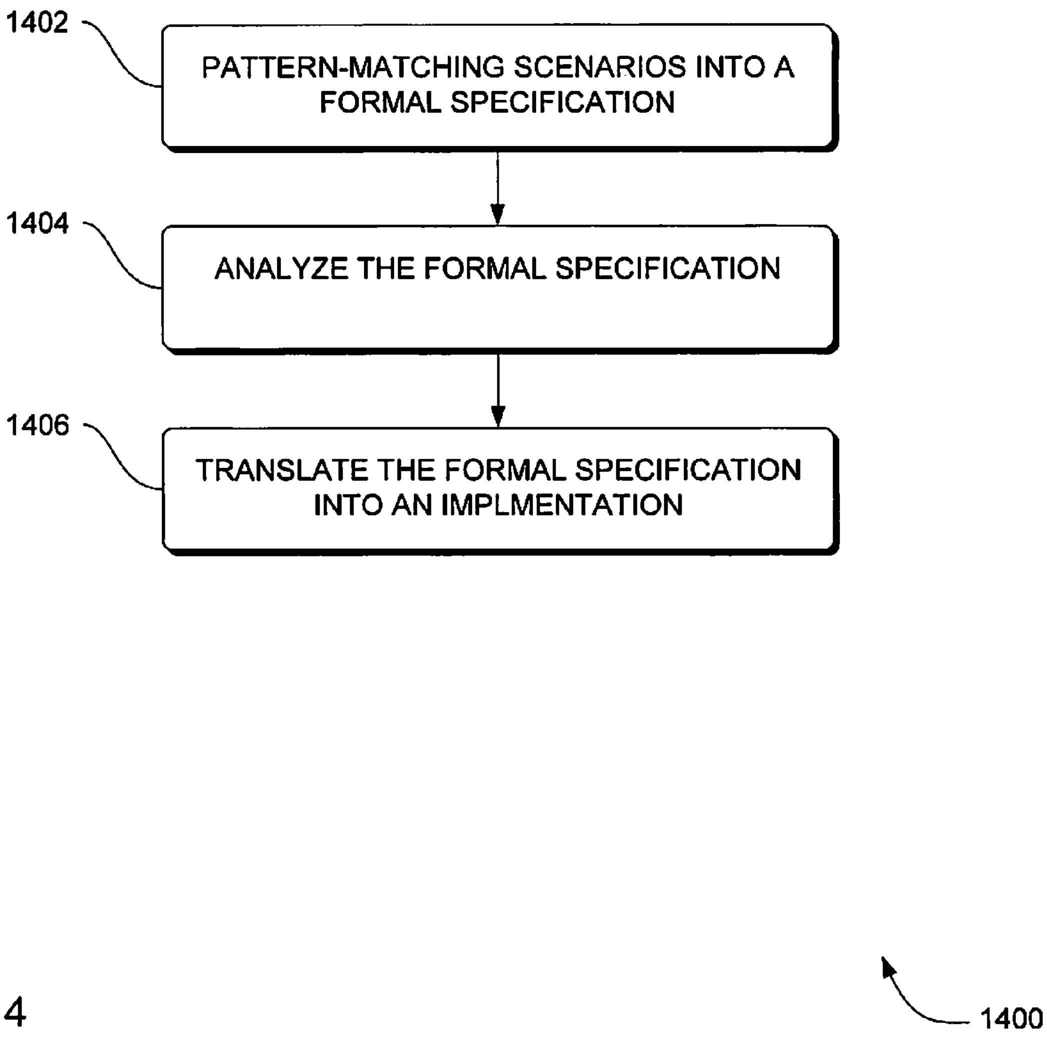
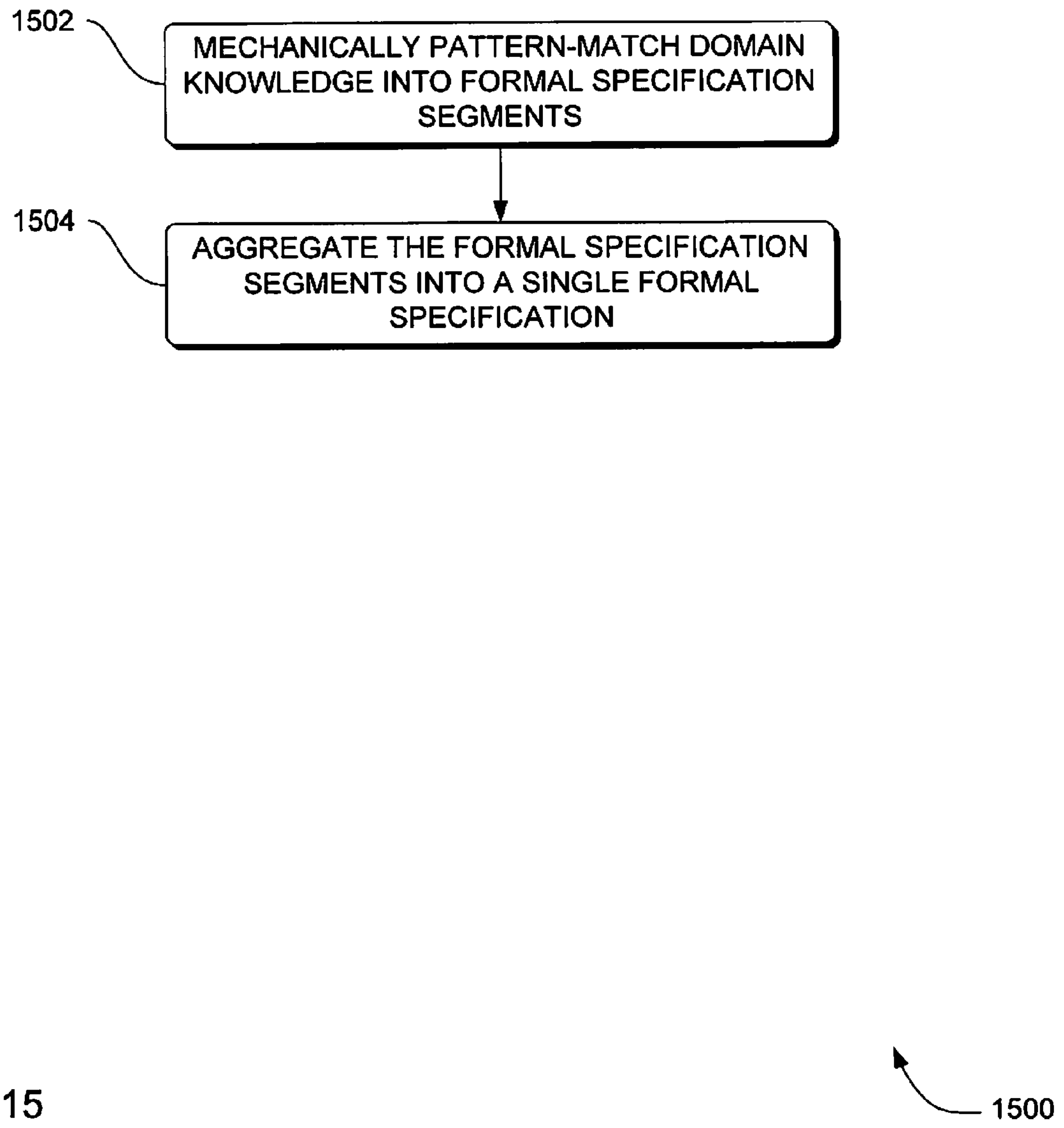

1402
PATTERN-MATCHING SCENARIOS INTO A FORMAL SPECIFICATION
1404
ANALYZE THE FORMAL SPECIFICATION
1406
TRANSLATE THE FORMAL SPECIFICATION INTO AN IMPLMENTATION
1400

FIG. 14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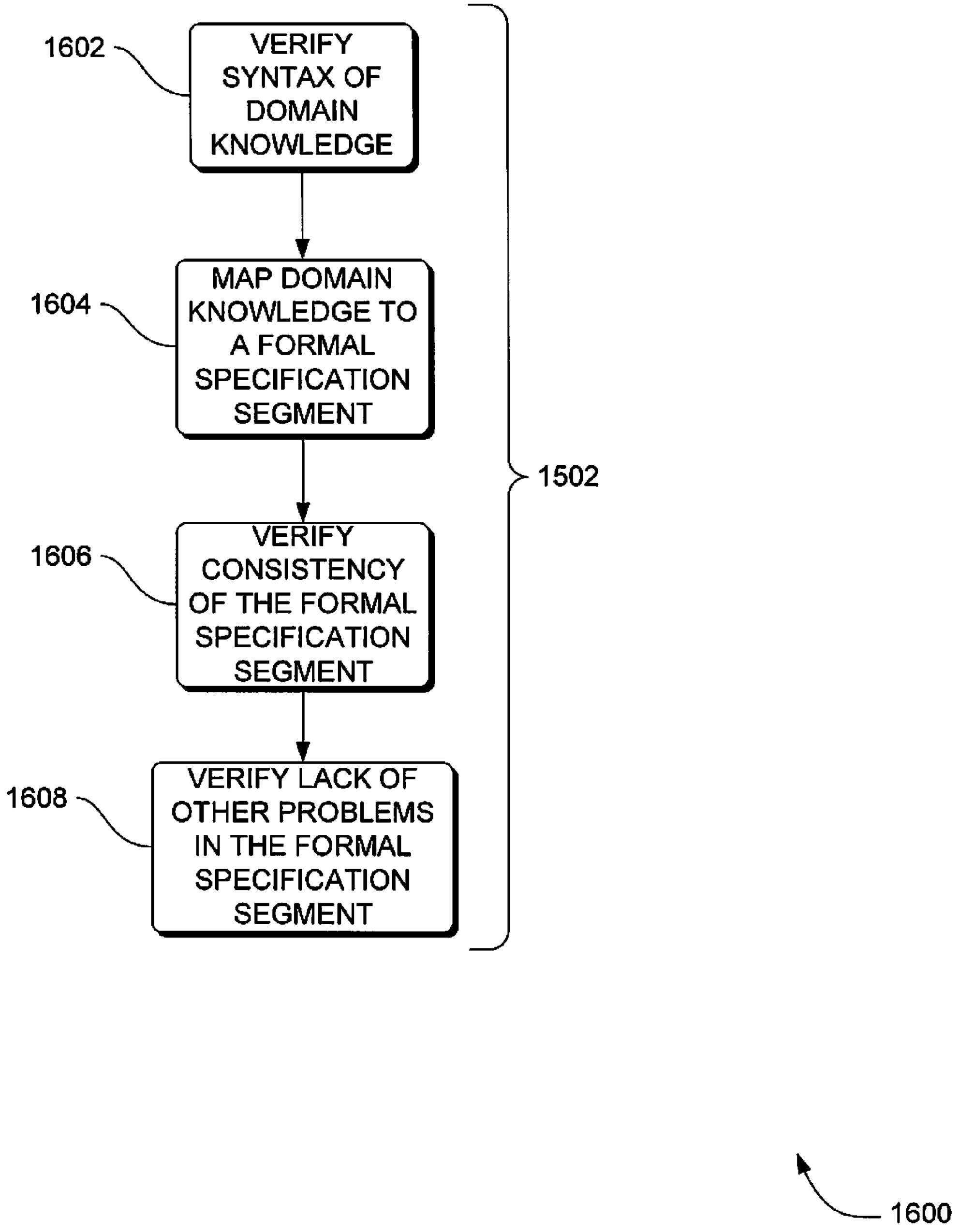
MECHANICALLY PATTERN-MATCH DOMAIN KNOWLEDGE INTO FORMAL SPECIFICATION SEGMENTS
1504
AGGREGATE THE FORMAL SPECIFICATION SEGMENTS INTO A SINGLE FORMAL SPECIFICATION
1500

FIG. 15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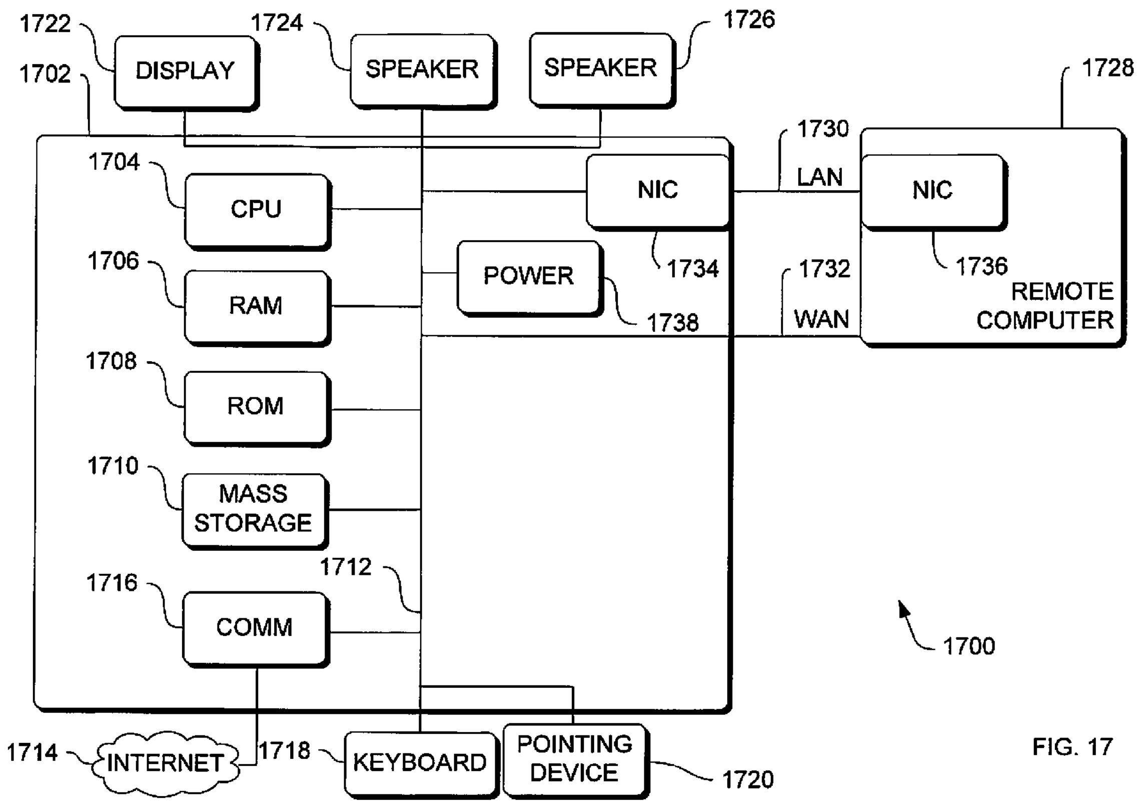
VERIFY SYNTAX OF DOMAIN KNOWLEDGE
1604
MAP DOMAIN KNOWLEDGE TO A FORMAL SPECIFICATION SEGMENT
1606
VERIFY CONSISTENCY OF THE FORMAL SPECIFICATION SEGMENT
1608
VERIFY LACK OF OTHER PROBLEMS IN THE FORMAL SPECIFICATION SEGMENT
1502
1600

FIG. 16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SPEAKER
SPEAKER
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RAM
POWER
1738
1732
WAN
REMOTE
COMPUTER
1708
ROM
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MASS
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INTERNET
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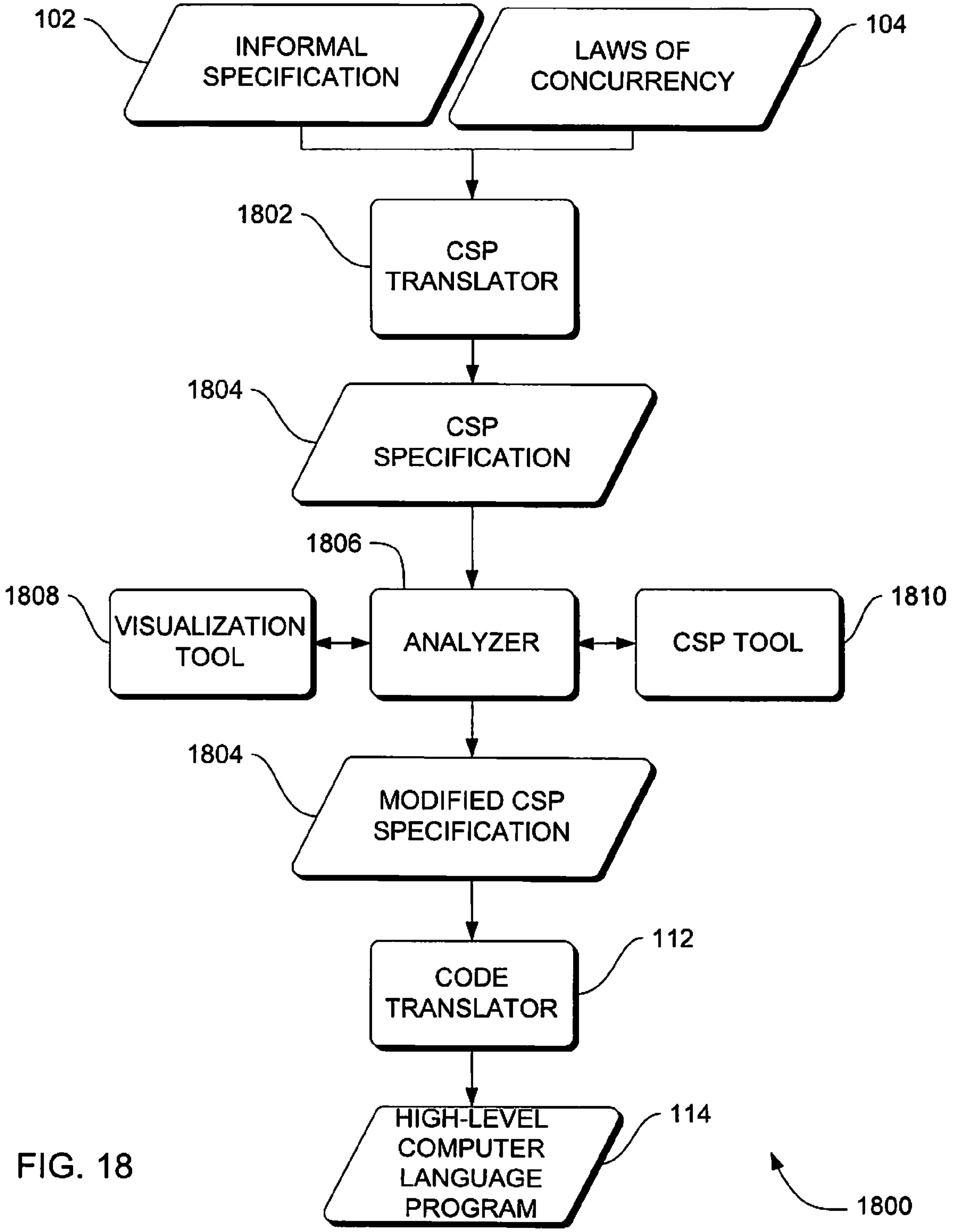
KEYBOARD
POINTING
DEVICE
1720

FIG. 17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VISUALIZATION TOOL
ANALYZER
CSP TOOL
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MODIFIED CSP SPECIFICATION
CODE TRANSLATOR
112
HIGH-LEVEL COMPUTER LANGUAGE PROGRAM
114
1800

FIG. 18

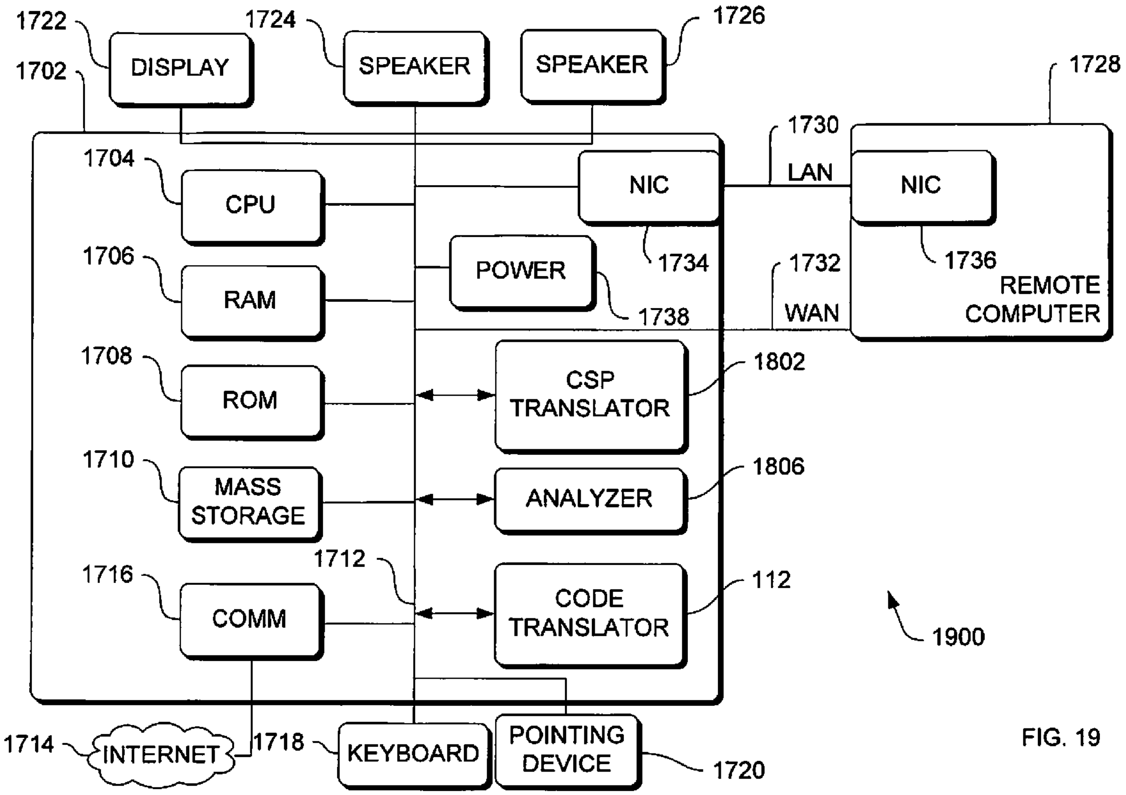
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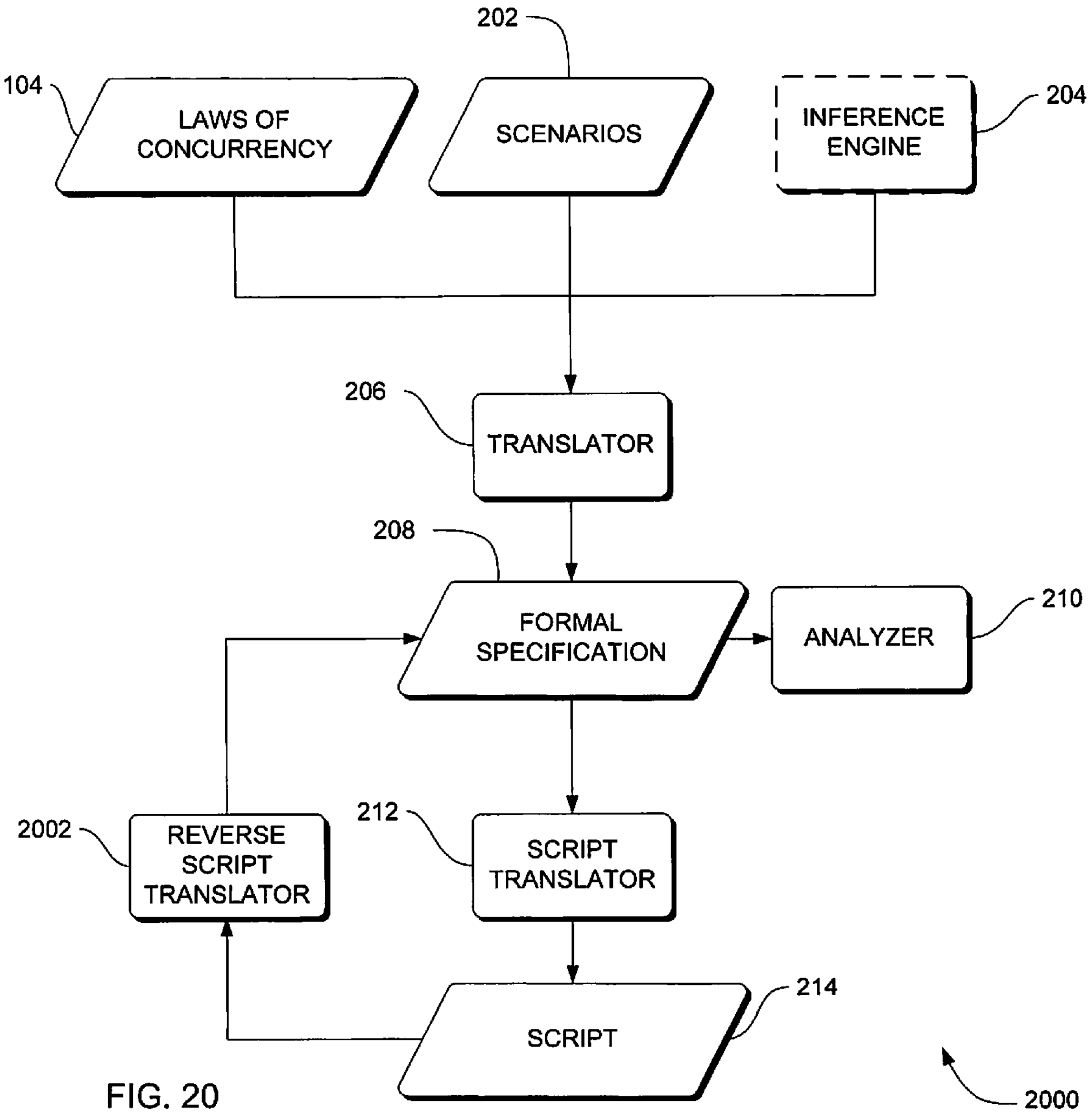
FIG. 19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SCRIPT TRANSLATOR
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FIG. 20

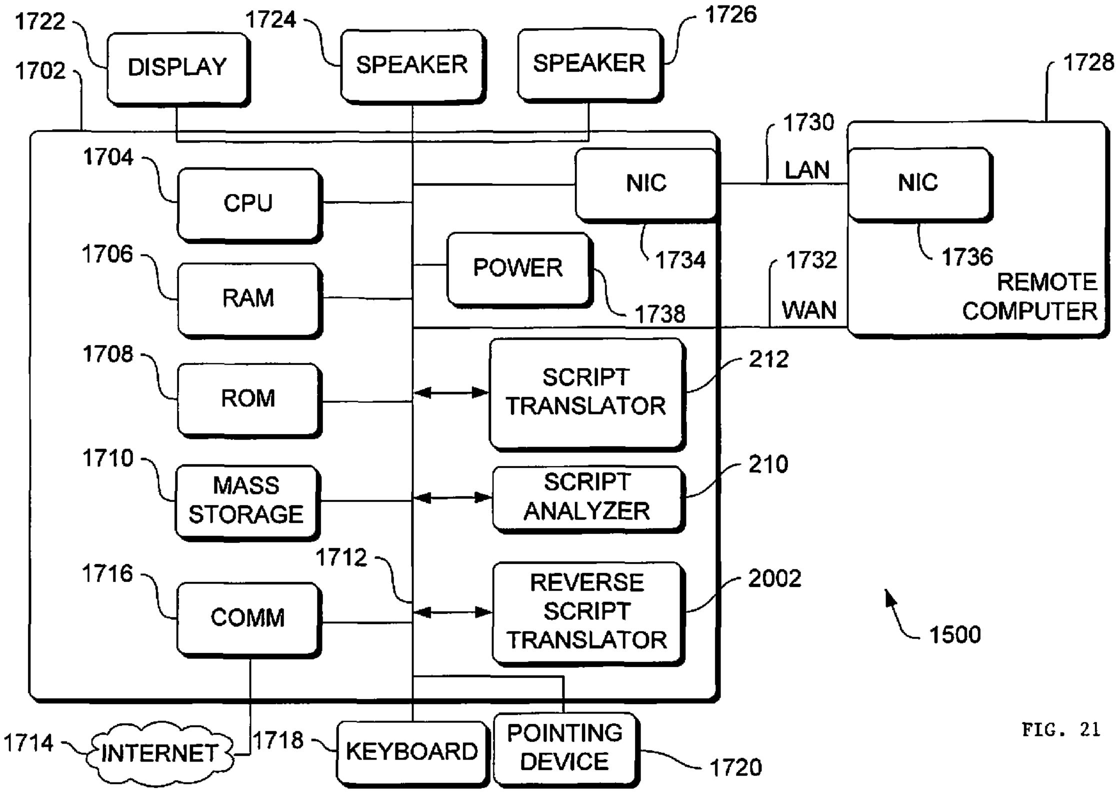
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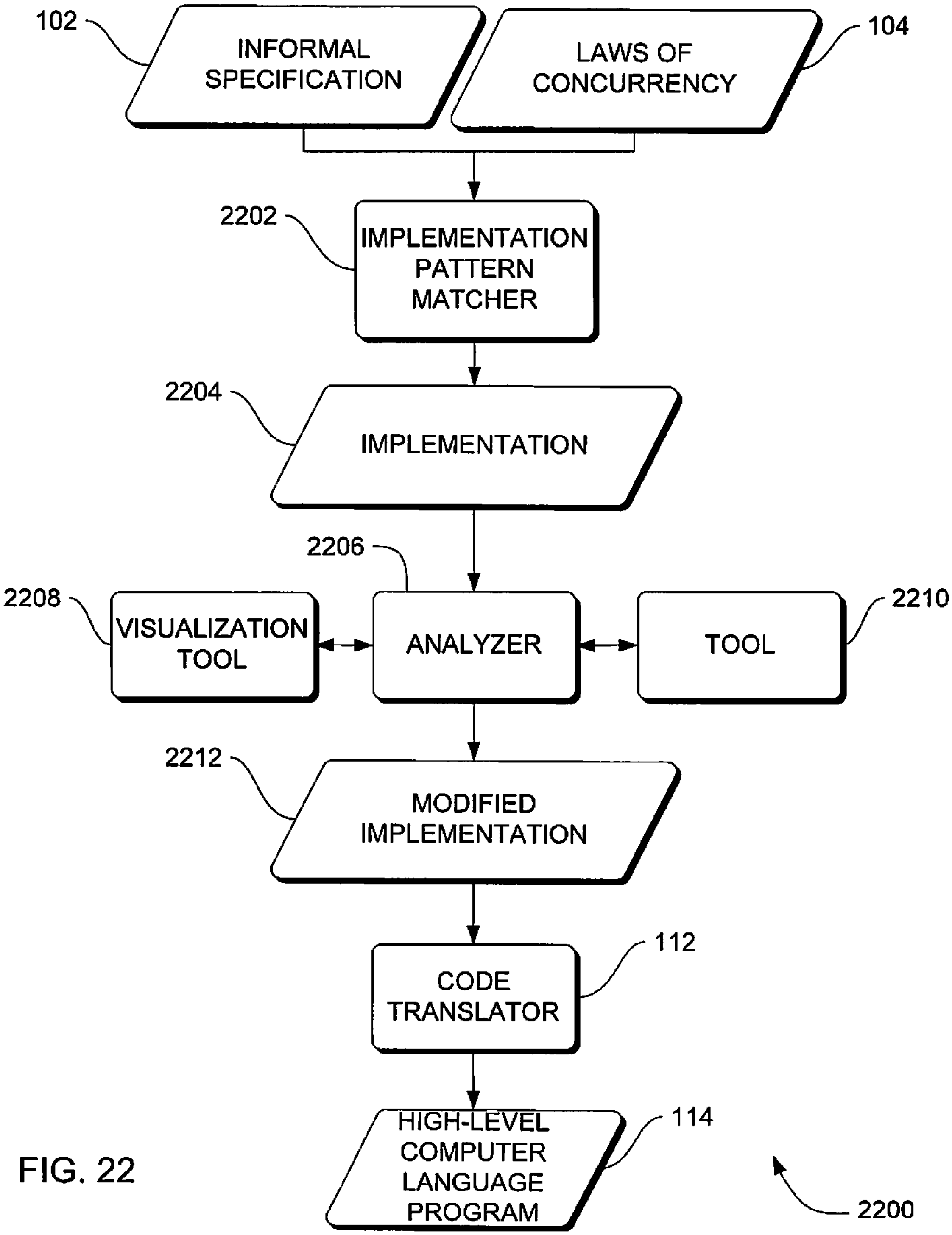
FIG. 21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VISUALIZATION TOOL
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FIG. 22

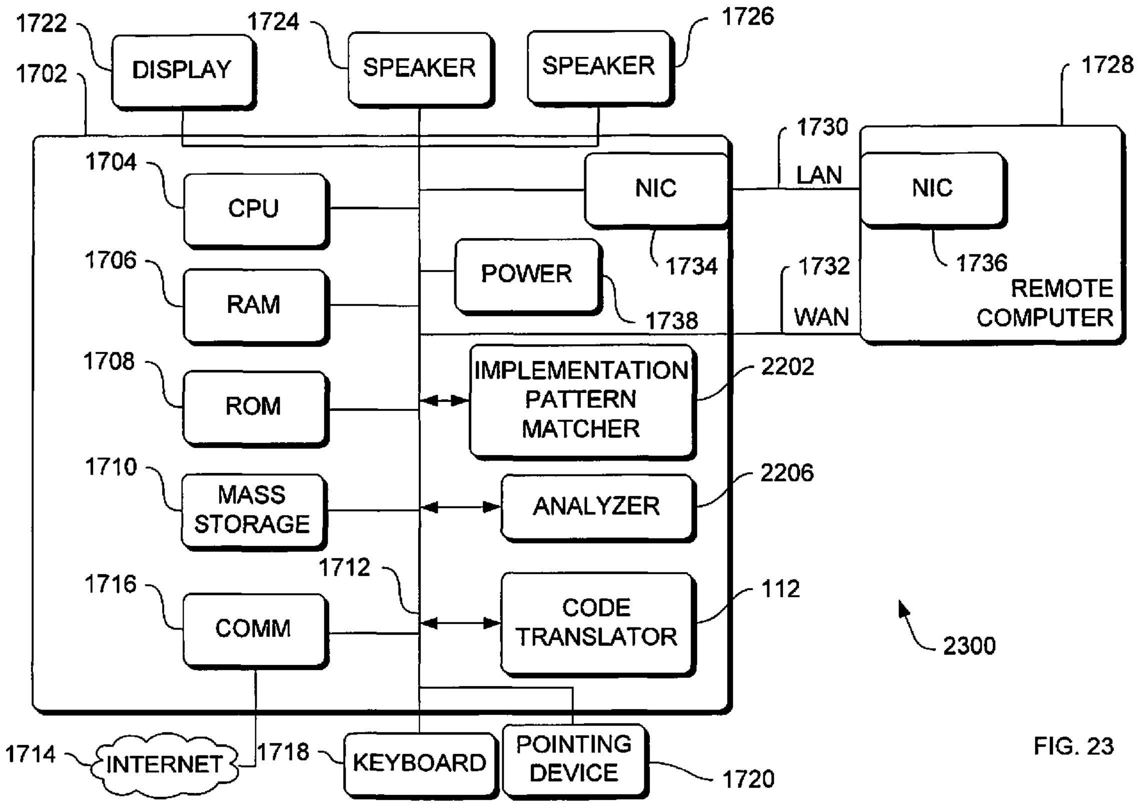
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FIG. 23

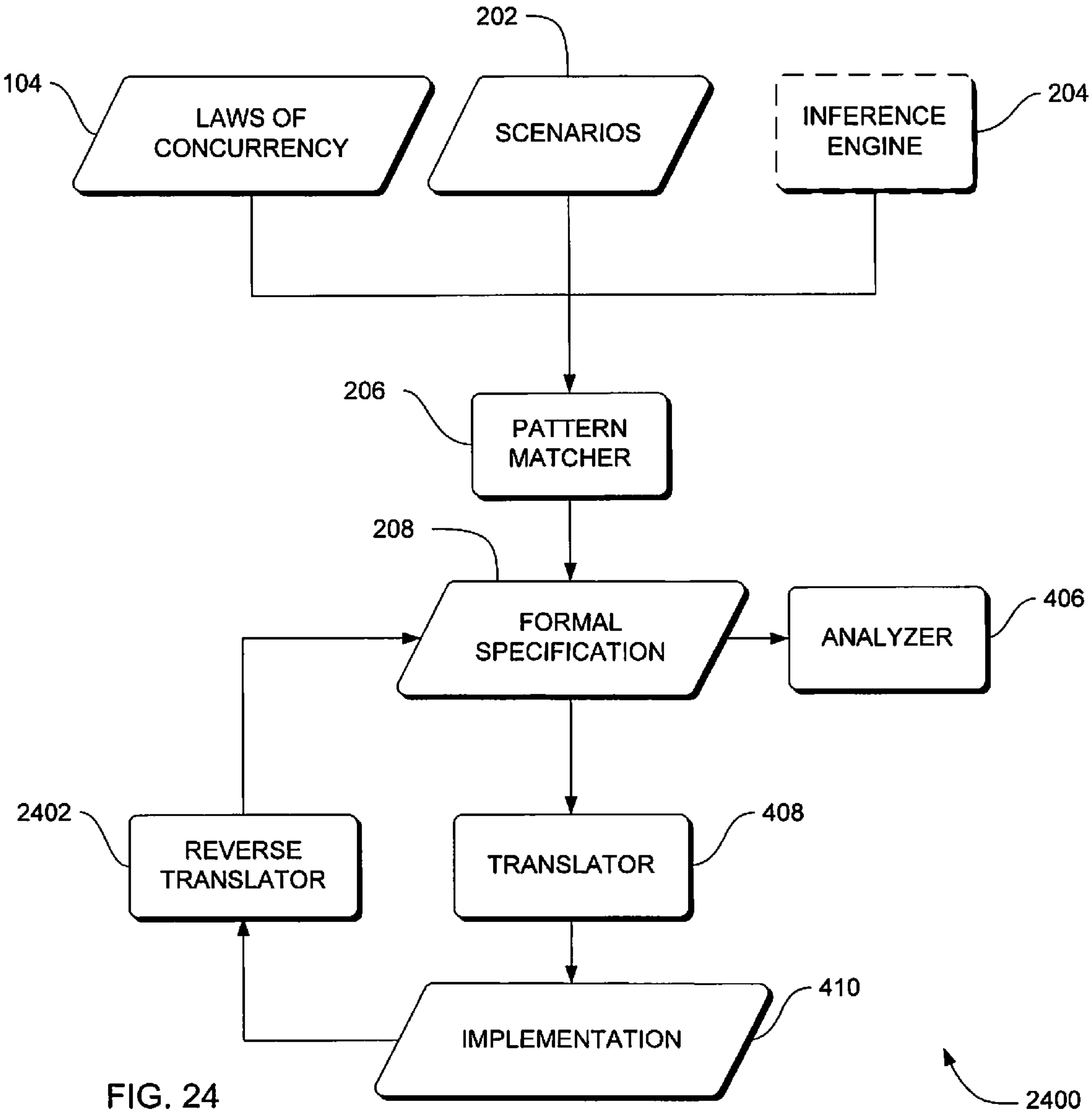
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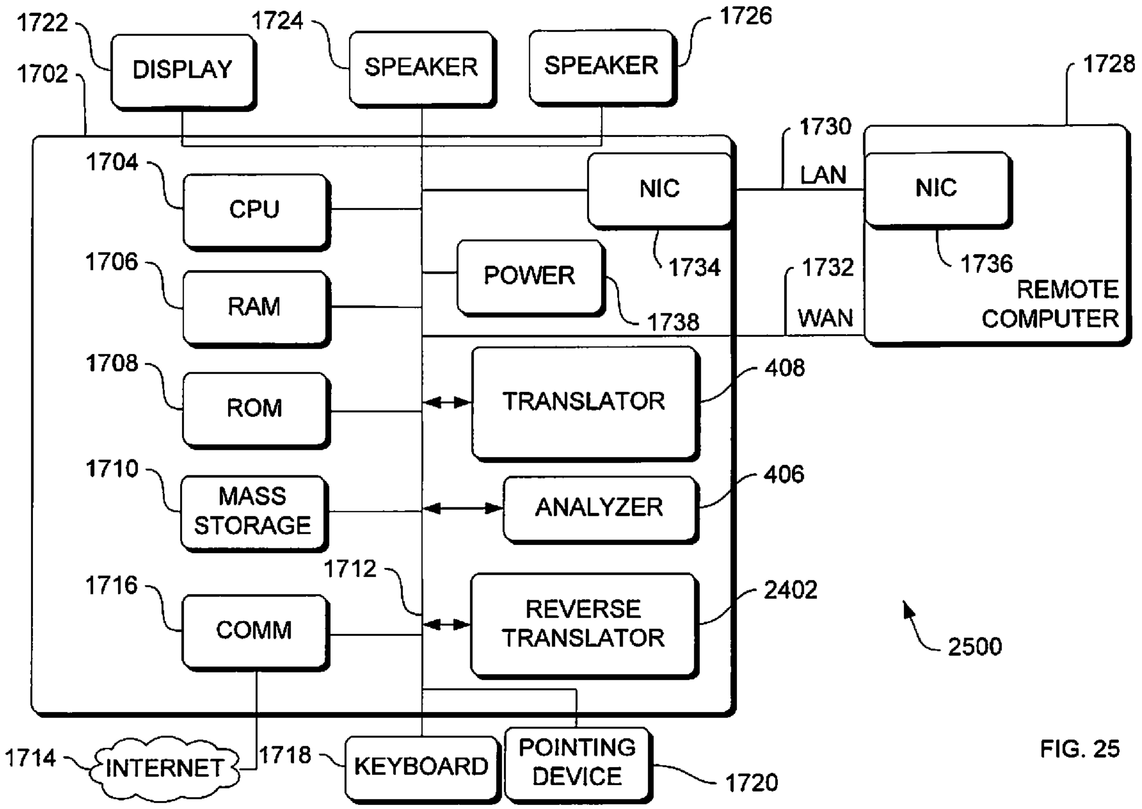
FIG. 24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POINTING
DEVICE
1720

FIG. 25

SYSTEMS, METHODS AND APPARATUS FOR PATTERN MATCHING IN PROCEDURE DEVELOPMENT AND VERIFICATION

RELATED APPLICATIONS

This application is a continuation-in-part of co-pending U.S. application Ser. No. 11/461,669 filed on Aug. 1, 2006 entitled "Systems, Methods and Apparatus for Procedure Development and Verification," which is a continuation-in-part of U.S. application Ser. No. 11/203,590 filed Aug. 12, 2005 now U.S. Pat. No. 7,739,671 entitled "Systems, Methods & Apparatus For Implementation Of Formal Specifications Derived From Informal Requirements," which is a continuation-in-part of U.S. application Ser. No. 10/533,376 filed Apr. 29, 2005 now U.S. Pat. No. 7,484,688 entitled "System and Method for Deriving a Process-based Specification."

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

FIELD OF THE INVENTION

This invention relates generally to software development processes and more particularly to validating a system implemented from requirements expressed in natural language or a variety of graphical notations.

BACKGROUND OF THE INVENTION

High dependability and reliability is a goal of all computer and software systems. Complex systems in general cannot attain high dependability without addressing crucial remaining open issues of software dependability. The need for ultra-high dependable systems increases continually, along with a corresponding increasing need to ensure correctness in system development. Correctness exists where the implemented system is equivalent to the requirements, and where this equivalence can be mathematically proven.

The development of a system may begin with the development of a requirements specification, such as a formal specification or an informal specification. A formal specification might be encoded in a high-level language, whereas requirements in the form of an informal specification can be expressed in restricted natural language, "if-then" rules, graphical notations, English language, programming language representations, flowcharts, scenarios or even using semi-formal notations such as unified modeling language (UML) use cases.

A scenario can be defined as a natural language text (or a combination of any, e.g. graphical, representations of sequential steps or events) that describes the software's actions in response to incoming data and the internal goals of the software. Some scenarios can also describe communication protocols between systems and between the components within the systems. Also, some scenarios can be known as UML use-cases. In some embodiments, a scenario describes one or more potential executions of a system, describing what happens in a particular situation, and what range of behaviors is expected from or omitted by the system under various conditions.

Natural language scenarios are usually constructed in terms of individual scenarios written in a structured natural language. Different scenarios can be written by different stakeholders of the system, corresponding to the different views the stakeholders have of how the system will perform, including alternative views corresponding to higher or lower levels of abstraction. Natural language scenarios can be generated by a user with or without mechanical or computer aid. The set of natural language scenarios provides the descriptions of actions that occur as the software executes. Some of these actions may be explicit and required, while others can be due to errors arising, or as a result of adapting to changing conditions as the system executes.

For example, if the system involves commanding space satellites, scenarios for that system can include sending commands to the satellites and processing data received in response to the commands. Natural language scenarios might be specific to the technology or application domain to which the natural language scenarios are applied. A fully automated general purpose approach covering all domains is technically prohibitive to implement in a way that is both complete and consistent. To ensure consistency, the domain of application might be purpose-specific. For example, scenarios for satellite systems might not be applicable as scenarios for systems that manufacture agricultural chemicals.

After completion of an informal specification that represents domain knowledge, the system is developed. A formal specification is not necessarily used by the developer in the development of a system.

In the development of some systems, computer readable code is generated. The generated code is typically encoded in a computer language, such as a high-level computer language. Examples of such languages include Java, C, C Language Integrated Production System (CLIPS), and Prolog.

One step in creating a system with high dependability and reliability can be verification and validation that the executable system accurately reflects the requirements. Validation of the generated code is sometimes performed through the use of a domain simulator, a very elaborate and costly approach that is computationally intensive. This process of validation via simulation rarely results in an unambiguous result and rarely results in uncontested results among systems analysts. In some examples, a system is validated through parallel mode, shadow mode operations with a human operated system. This approach can be very expensive and exhibit severely limited effectiveness. In some complex systems, this approach leaves vast parts of possible execution paths forever unexplored and unverified.

During the life cycle of a system, requirements typically evolve. Manual change to the system creates a risk of introducing new errors and necessitates retesting and revalidation, which can greatly increase the cost of the system. Often, needed changes are not made due to the cost of verifying/validating consequential changes in the rest of the system. Sometimes, changes are simply made in the code and not reflected in the specification or design, due to the cost or due to the fact that those who generated the original specification or design are no longer available.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art to reduce system development time, reduce the amount of testing required of a new system, and improve confidence that the system reflects the requirements.

BRIEF DESCRIPTION OF THE INVENTION

The above-mentioned shortcomings, disadvantages and problems are addressed herein, which will be understood by reading and studying the following discussion.

Some embodiments of the systems, methods and apparatus described herein provide automated analysis, validation, verification, and generation of complex procedures. The generation is performed by pattern matching with set comprehensions without a theorem-prover or a formal proof of correctness. The systems, methods and apparatus may include pattern-matching an equivalent formal model from an informal specification. Such a model can be analyzed for contradictions, conflicts, use of resources before the resources are available, competition for resources, and so forth. From such a formal model, an implementation can be automatically generated in a variety of notations. Some implementations may include traditional programming language code, machine language code, scripts, and/or procedures. The approach can improve the resulting implementation, which, in some embodiments, is provably equivalent to the procedures described at the outset, which in turn can improve confidence that the system reflects the requirements, and in turn reduces system development time and reduces the amount of testing required of a new system. Moreover, in some embodiments, two or more implementations can be "reversed" to appropriate formal models, the models can be combined, and the resulting combination checked for conflicts. Then, the combined, error-free model can be used to generate a new (single) implementation that combines the functionality of the original separate implementations, and may be more likely to be correct.

In at least one embodiment, systems, methods and apparatus are provided through which scenarios are pattern-matched without human intervention into a formal specification or other process-based specification segment. In some embodiments, the formal specification is converted to an implementation. In some embodiments, the formal specification is analyzed for errors, which reduces errors in the formal specification. In some embodiments, the formal specification is translated back to an informal specification expressed in natural language or a plurality of graphical notations. The scenario or complex set of procedures can be designed for the assembly and maintenance of devices (whether by human or robots), for business operation, or for experimentation in a laboratory (such as might be used by the bioinformatics community).

In other embodiments, a system may include an inference engine and a pattern matcher, the pattern matcher being operable to receive scenarios and to generate, in reference to an inference engine, a formal specification. The system may also include an analyzer operable to perform model verification/checking and determine existence of omissions, deadlock, livelock, and race conditions or other problems and inconsistencies in either the formal specification or the scenario.

In yet other embodiments, a method may include pattern-matching requirements expressed informally in natural language or a plurality of graphical notations to a formal specification or scenario, and analyzing the formal specification or scenario.

Systems, clients, servers, methods, and computer-readable media of varying scope are described herein. In addition to the embodiments and advantages described in this summary, further embodiments and advantages will become apparent by reference to the drawings and by reading the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram that provides an overview of a system to generate a high-level computer source code program from an informal specification, according to an embodiment of the invention;

FIG. **2** is a block diagram that provides an overview of a system to engineer a script or procedure from scenarios, according to an embodiment of the invention;

FIG. **3** is a block diagram that provides an overview of a system to generate a high-level computer source code program from an informal specification, according to an embodiment that includes a pattern matcher;

FIG. **4** is a block diagram that provides an overview of a system to engineer an implementation from scenarios, according to an embodiment that may include a pattern matcher and an inference engine;

FIG. **5** is a flowchart of a method to generate an executable system from an informal specification, according to an embodiment;

FIG. **6** is a flowchart of a method to translate mechanically each of a plurality of requirements of the informal specification to a plurality of process-based specification segments, according to an embodiment;

FIG. **7** is a flowchart of a method to verify the syntax of a set of scenarios, translate the set of scenarios to a formal specification, verify the consistency of the formal specification, and verify the absence of other problems, according to an embodiment;

FIG. **8** is a flowchart of a method to validate/update scenarios of a system, according to an embodiment;

FIG. **9** is a flowchart of a method to translate each of a plurality of requirements of the domain knowledge to a plurality of formal specification segments, and formally compose the plurality of formal specification segments into a single equivalent specification, and translate the single formal specification into a script, according to an embodiment;

FIG. **10** is a flowchart of a method to generate a formal specification from scenarios, according to an embodiment;

FIG. **11** is a flowchart of a method to generate an executable system from an informal specification, according to an embodiment;

FIG. **12** is a flowchart of a method to translate mechanically each of a plurality of requirements of the informal specification to a plurality of process-based specification segments, according to an embodiment;

FIG. **13** is a flowchart of a method to validate/update a system, according to an embodiment;

FIG. **14** is a flowchart of a method to pattern-match scenarios into a formal specification, analyze the formal specification, and translate the formal specification into CSP, according to an embodiment;

FIG. **15** is a flowchart of a method to translate each of a plurality of requirements of the domain knowledge to a plurality of formal specification segments, and formally compose the plurality of formal specification segments into a single equivalent specification, according to an embodiment;

FIG. **16** is a flowchart of a method to generate a formal specification from domain knowledge, according to an embodiment;

FIG. **17** is a block diagram of the hardware and operating environment in which different embodiments can be practiced, according to an embodiment;

FIG. **18** is a block diagram of a particular CSP implementation of an apparatus to generate a high-level computer source code program from an informal specification, according to an embodiment;

FIG. **19** is a block diagram of a hardware and operating environment in which a particular CSP implementation of FIG. **18** is implemented, according to an embodiment;

FIG. **20** is a block diagram of a particular implementation of an apparatus capable to translate scenarios to a formal specification, optionally analyze the formal specification and translate the formal specification to a script and reverse engineer (translate) a script into a formal specification and optionally analyze the formal specification, according to an embodiment;

FIG. **21** is a block diagram of a hardware and operating environment in which components of FIG. **20** can be implemented, according to an embodiment.

FIG. **22** is a block diagram of a particular CSP pattern-matching implementation of an apparatus to generate a high-level computer source code program from an informal specification, according to an embodiment;

FIG. **23** is a block diagram of a hardware and operating environment in which a particular CSP pattern-matching implementation of FIG. **22** can be implemented, according to an embodiment;

FIG. **24** is a block diagram of a particular implementation of an apparatus capable of pattern-matching scenarios to a formal specification, optionally analyzing the formal specification and translating the formal specification to an implementation and reverse engineering (translating) an implementation into a formal specification and optionally analyzing the formal specification, according to an embodiment; and

FIG. **25** is a block diagram of a hardware and operating environment in which components of FIG. **24** can be implemented, according to an embodiment.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown, by way of illustration, specific embodiments which can be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the embodiments, and it is to be understood that other embodiments can be utilized and that logical, mechanical, electrical and other changes can be made without departing from the scope of the embodiments. The following detailed description is, therefore, not to be taken in a limiting sense.

The detailed description is divided into six sections. In the first section, embodiments of a system level overview are described. In the second section, embodiments of methods are described. In the third section, embodiments of the hardware and the operating environment, in conjunction with which embodiments can be practiced, is described. In the fourth section, particular CSP implementations of embodiments are described. In the fifth section, particular apparatus embodiments are described. Finally, in the sixth section, a conclusion of the detailed description is provided.

System Level Overview

FIG. **1** is a block diagram that provides an overview of a system **100** to generate a high-level computer source code program from an informal specification, according to an embodiment. FIG. **2** is a block diagram that provides an overview of a system **200** to generate a formal specification and an implementation from descriptions of a system, according to embodiments. FIG. **3** is a block diagram that provides an overview of a system to generate a high-level computer source code program from an informal specification, according to an embodiment that includes a pattern matcher. FIG. **4** is a block diagram that provides an overview of a system to generate a formal specification and an implementation from descriptions of a system, according to an embodiment that includes a pattern matcher and an inference engine.

System **100** may solve the need in the art for an automated, generally applicable way to produce a system that can be a provably correct implementation of an informal design specification that does not require, in applying the system to any particular problem or application, the use of a theorem-prover.

System **100** may be a software development system that includes a data flow and processing points for the data. System **100** may be representative of (i) computer applications and electrical engineering applications such as chip design and other electrical circuit design, (ii) business management applications in areas such as workflow analysis, (iii) artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, (iv) highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, and (v) any other area involving process, sequence or algorithm design. According to the disclosed embodiments, system **100** may mechanically convert different types of specifications (either natural language scenarios or descriptions which are effectively pre-processed scenarios) into process-based formal specifications on which model checking and other mathematics-based verifications can be performed, and then optionally can convert the formal specification into code.

System **100** may include an informal specification **102** having a plurality of rules or requirements. The informal specification can be expressed in restricted natural language, graphical notations, English language, programming language representations, scenarios or even using semi-formal notations such as unified modeling language (UML) use cases. One skilled in the art will recognize that other languages and graphic indicators may exist that fall within the scope of this invention.

A scenario may be natural language text (or a combination of any (possibly graphical) representations of sequential steps or events) that describes the software's actions in response to incoming data and the internal goals of the software. Scenarios also may describe communication protocols between systems and between the components within the systems. Scenarios also may be known as use cases. A scenario can describe one or more potential executions of a system, describing what happens in a particular situation, and what range of behaviors is expected from or omitted by the system under various conditions.

System **100** may also include a set of laws of concurrency **104**. Laws of concurrency **104** can be rules detailing equivalences between sets of processes combined in various ways, and/or relating process-based descriptions of systems or system components to equivalent sets of traces. An example of the laws of concurrency **104** is given in "Concurrent Systems: Formal Development in CS by M. G. Hinchey an S. A. Jarvis, McGraw-Hill International Series in Software Engineering, New York and London, 1995, which is herein incorporated by reference in its entirety. Laws of concurrency **104** may be expressed in any suitable language for describing concurrency. These languages may include, but are not limited to, CSP (Communicating Sequential Processes), CCS (Calculus of Communicating Systems) and variants of these languages.

The informal specification **102** and a set of laws of concurrency **104** can be received by a translator **106**, which may be a mechanical translator. The plurality of rules or requirements of the informal specification **102** may be translated mechanically to a process-based specification **108** or other formal specification language representation. The mechanical aspect can mean that no manual intervention in the translation is provided. In some embodiments, the process-based specification **108** is an intermediate notation or language of sequential process algebra such as Hoare's language of Communicating Sequential Processes (CSP).

The process-based specification **108** may be mathematically and provably equivalent to the informal specification **102**. Mathematically equivalent does not necessarily mean mathematically equal. Mathematical equivalence of A and B means that A implies B and B implies A. Note that applying the laws of concurrency **104** to the process-based specification **108** would allow for the retrieval of a trace-based specification that may be equivalent to the informal specification **102**. Note that the process-based specification may be mathematically equivalent to rather than necessarily equal to the original informal specification **108**. This indicates that the process may be reversed, allowing for reverse engineering of existing systems, or for iterative development of more complex systems.

In some embodiments, the system includes an analyzer **110** to determine various properties such as existence of omissions, deadlock, livelock, and race conditions in the process-based specification **108**.

System **100** may also include a code translator **112** to translate the plurality of process-based specification segments **108** to a set of instructions in a high-level computer language program **114**, such as the Java language.

System **100** may be operational for a wide variety of informal specification languages and applications, thus system **100** can be generally applicable. Such applications will be apparent to one skilled in the art and may include distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, chemical plant operation and control, and autonomous systems.

System **100** can provide mechanical regeneration of the executable system when requirements dictate a change in the high level specification. In system **100**, all that may be required to update the generated application may be a change in the informal specification **102**, and then the changes and validation can ripple through in a mechanical process when system **100** operates. This also can allow the possibility of cost effectively developing competing designs for a product and implementing each to determine the best one.

In some embodiments, system **100** does not include a theorem-prover to infer the process-based specification segments from the informal specification. However, the plurality of process-based specification segments **108** may be provably correct implementations of the informal specification **102**, provided the developer of an instance of system **100** has properly used a theorem-prover (not shown) to prove that the translator **106** correctly translates informal specifications into formal specifications.

Some embodiments of system **100** operate in a multi-processing, multi-threaded operating environment on a computer, such as computer **1702** in FIG. **17**. While the system **100** is not limited to any particular informal specification **102**, plurality of rules or requirements, set of laws of concurrency **104**, translator **106**, process-based specification **108**, analyzer **110**, code translator **112** and high-level computer language program **114**, for sake of clarity a simplified informal specification **102**, plurality of rules or requirements, set of laws of concurrency **104**, translator **106**, process-based specification **108**, analyzer **110**, code translator **112**, and high-level computer language program **114** are illustrated.

System **100** may relate to the field of chemical or biological process design or mechanical system design, and, generally to any field where the behaviors exhibited by a process to be designed can be described by a set of scenarios expressed in natural language, or some appropriate graphical notation or textual notation.

FIG. **2** is a block diagram that provides an overview of a system **200** to engineer a script or procedure from scenarios, according to an embodiment. System **200** may solve the need in the art for an automated, generally applicable way to verify that an implemented script is a provably correct implementation of a set of scenarios.

One embodiment of the system **200** may be a software development system that includes a data flow and processing points for the data. According to some embodiments, system **200** can convert scenarios into a script on which model checking and other mathematics-based verifications can then be performed.

The system **200** can include a plurality of scenarios **202**. The scenarios **202** can be written in a particular syntax, such as constrained natural language or graphical representations. The scenarios **202** can embody software applications, although one skilled in the art will recognize that other systems fall within the purview of this invention.

In at least one embodiment, the scenarios **202** may be received by a translator **206**. In some embodiments, the optional inference engine **204** might be referenced by the translator **206** when the scenarios **202** are translated by the translator **206** into a formal specification **208**. Subsequently, the formal specification **208** can be translated by script translator **212** into a script **214** in some appropriate scripting language. In some embodiments, no manual intervention in the translation is provided. Those skilled in the art will readily understand that other appropriate notations and/or languages exist that are within the scope of this invention.

In some embodiments, system **200** can include an analyzer **210** to determine various properties of the formal specification, such as the existence of omissions, deadlock, livelock, and race conditions, as well as other conditions, in the formal specification **208**, although one skilled in the art will recognize that other additional properties can be determined by the analyzer **210**. The analyzer **210** may solve the need in the prior art to reduce errors.

The terms "scripts" and "procedures" can be used interchangeably. Scripts can encompass not only instructions written in programming languages (such as Python, awk, etc., as described) but also languages for physical (electro-mechanical) devices and even in constrained natural language instructions or steps or checklists to be carried out by human beings such as, but not limited to, an astronaut.

Scripting languages are computer programming languages initially used only for simple, repeated actions. The name "scripting languages" comes from a written script such as a screenplay, where dialog is repeated verbatim for every performance. Early script languages were often called batch languages or job control languages. A script is typically interpreted rather than compiled, but not always. Scripting languages may also be known as scripting programming languages or script languages.

Many such languages can be quite sophisticated and have been used to write elaborate programs, which are often still called scripts even though the applications of scripts are well beyond automating simple computer tasks. A script language can be found at almost every level of a computer system. Besides being found at the level of the operating system, scripting languages appear in computer games, web applications, word processing documents, network software and more. Scripting languages favor rapid development over efficiency of execution; scripting languages are often implemented with interpreters rather than compilers; and scripting languages are effective in communication with program components written in other languages.

Many scripting languages emerged as tools for executing one-off tasks, particularly in system administration. One way of looking at scripts is as "glue" that puts several components together; thus scripts are widely used for creating graphical user interfaces or executing a series of commands that might otherwise have to be entered interactively through keyboard at the command prompt. The operating system usually offers some type of scripting language by default, widely known as a shell script language.

Scripts are typically stored only in their plain text form (as ASCII) and interpreted, or compiled, each time prior to being invoked.

Some scripting languages are designed for a specific domain, but often it is possible to write more general programs in that language. In many large-scale projects, a scripting language and a lower level programming language are used together, each lending its particular strengths to solve specific problems. Scripting languages are often designed for interactive use, having many commands that can execute individually, and often have very high level operations (for example, in the classic UNIX shell (sh), most operations are programs).

Such high level commands simplify the process of writing code. Programming features such as automatic memory management and bounds checking can be taken for granted. In a 'lower level' or non-scripting language, managing memory and variables and creating data structures tend to consume more programmer effort and lines of code to complete a given task. In some situations this is well worth it for the resulting fine-grained control. The scripter typically has less flexibility to optimize a program for speed or to conserve memory.

For the reasons noted above, it is usually faster to program in a scripting language, and script files are typically much smaller than programs with equivalent functionality in conventional programming languages such as C.

Scripting languages may fall into eight primary categories: Job control languages and shells, macro languages, application-specific languages, web programming languages, text processing languages, general-purpose dynamic languages, extension/embeddable languages, and extension/embeddable languages.

In regards to job control scripting languages and shells, a major class of scripting languages has grown out of the automation of job control—starting and controlling the behavior of system programs. Many of these languages' interpreters double as command-line interfaces, such as the Unix shell or the MS-DOS COMMAND.COM. Others, such as AppleScript, add scripting capability to computing environments lacking a command-line interface. Examples of job control scripting languages and shells include AppleScript, ARexx (Amiga Rexx), bash, csh, DCL, 4NT, JCL, ksh, MS-DOS batch, Windows PowerShell, REXX, sh, and Winbatch

In regards to macro scripting languages, with the advent of Graphical user interfaces, a specialized kind of scripting language for controlling a computer evolved. These languages, usually called Macro languages, interact with the same graphic windows, menus, buttons and such that a person does. Macro language scripts are typically used to automate repetitive actions or configure a standard state. Macro language scripts can be used to control any application running on a GUI-based computer, but in practice the support for such languages depends on the application and operating system. Examples of macro scripting languages include AutoHotkey, AutoIt, and Expect.

In regards to application-specific scripting languages, many large application programs include an idiomatic scripting language tailored to the needs of the application user. Likewise, many computer game systems use a custom scripting language to express the programmed actions of non-player characters and the game environment. Languages of this sort are designed for a single application and, while application-specific scripting languages can superficially resemble a specific general-purpose language (e.g. QuakeC, modeled after C), application-specific scripting languages have custom features which distinguish such languages. Examples of application-specific scripting languages include, Action Code Script, ActionScript, AutoLISP, BlobbieScript [1], Emacs Lisp, HyperTalk, IRC script, Lingo, Cana Embedded Language, mIRC script, NWscript, QuakeC, UnrealScript, Visual Basic for Applications, VBScript, and ZZT-oop.

In regards to web programming scripting languages, an important type of application-specific scripting language is one used to provide custom functionality to internet web pages. Web programming scripting languages are specialized for internet communication and use web browsers for their user interface. However, most modern web programming scripting languages are powerful enough for general-purpose programming. Examples of web programming scripting language include ColdFusion (Application Server), Lasso, Miva, and SMX.

In regards to text processing scripting languages, the processing of text-based records is one of the oldest uses of scripting languages. Many text processing languages, such as Unix's awk and, later, PERL, were originally designed to aid system administrators in automating tasks that involved Unix text-based configuration and log files. PERL is a special case—originally intended as a report-generation language, it has grown into a full-fledged applications language in its own right. Examples of text processing scripting languages include awk, PERL, sed and XSLT.

In regards to general-purpose dynamic scripting languages, some languages, such as PERL, began as scripting languages but developed into programming languages suitable for broader purposes. Other similar languages—frequently interpreted, memory-managed, dynamic—have been described as "scripting languages" for these similarities, even if general-purpose dynamic scripting languages are more commonly used for applications programming. Examples of general-purpose dynamic scripting languages include APL, Dylan, Groovy, MUMPS (M), newLISP, PERL, PHP, Python, Ruby, Scheme, Smalltalk, SuperCard, and Tool command language (TCL). TCL was created as an extension language but has come to be used more frequently as a general purpose language in roles similar to Python, PERL, and Ruby.

In regards to extension/embeddable languages, a small number of languages have been designed for the purpose of replacing application-specific scripting languages, by being embeddable in application programs. The application programmer (working in C or another systems language) includes "hooks" where the scripting language can control the application. These languages serve the same purpose as application-specific extension languages, but with the advantage of allowing some transfer of skills from application to application. Examples of extension/embeddable script languages include Ch (C/C++ interpreter), ECMAScript a.k.a. DMDScript, JavaScript, JScript, GameMonkeyScript, Guile, ICI, Squirrel, Lua, TCT, and REALbasic Script (RBScript).

JavaScript began as and primarily still is a language for scripting inside of web browsers, however, the standardization of the language as ECMAScript has made JavaScript widely adopted as a general purpose embeddable language.

Other scripting languages include BeanShell (scripting for Java), CobolScript, Escapade (server side scripting), Euphoria, F-Script, Ferite, Groovy, Gui4Cli, To, KiXtart, Mondrian, Object REXX, Pike, Pliant, REBOL, ScriptBasic, Shorthand Language, Simkin, Sleep, StepTalk, and Visual DialogScript.

In some embodiments, the script **214** can be mathematically and provably equivalent to the scenarios **202**. Mathematically equivalent does not necessarily mean mathematically equal. Mathematical equivalence of A and B means that A implies B and B implies A. Note that the script **214** of some embodiments can be mathematically equivalent to, rather than necessarily equal to, the scenarios **202**.

In some embodiments, the formal specification **208** can be a process-based specification, such as process algebra encoded notation. The process algebra encoded notation is a mathematically notated form. This embodiment may satisfy the need in the art for an automated, mathematics-based process for requirements validation that does not require large computational facilities.

In some embodiments, the scenarios **202** of system **200** can specify allowed situations, events and/or results of a software system. In that sense, the scenarios **202** can provide a very abstract specification of the software system.

Some embodiments of system **200** can be operational for a wide variety of rules, computer instructions, computer languages and applications; thus, system **200** may be generally applicable. Such applications can include, without limitation, space satellite control systems, distributed software systems, sensor networks, robot operations, complex scripts for spacecraft integration and testing, chemical plant operation and control, autonomous systems, electrical engineering applications such as chip design and other electrical circuit design, business management applications in areas such as workflow analysis, artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, and any other area involving process, sequence or algorithm design. Hence, one skilled in the art will recognize that any number of other applications not listed can fall within the scope of this invention.

Some embodiments of the system **200** can provide mechanical or automatic generation of the script **214**, in which human intervention is not required. In at least one embodiment of the system **200**, all that may be required to update the generated application is a change in the scenarios **202**, in which case the changes and validation can ripple through the entire system without human intervention when system **200** operates. This also allows the possibility of cost effectively developing competing designs for a product and implementing each to determine the best one.

Some embodiments of the system **200** may not include an automated logic engine, such as a theorem-prover or an automated deduction engine, to infer the script **214** from the scenarios **202**. However, the script **214** can be a provably correct version of the scenarios **202**.

Thus, in regards to scripts and complex procedures, automatic code generation of system **200** can generate procedures/scripts in suitable scripting language or device control language (such as for a robot) that would provide the procedures, once validated, to be automatically transformed into an implementation. Additionally, system **200** can be used to "reverse engineer" existing procedures/scripts so that the existing procedures/scripts can be analyzed and corrected and recast in a format and form that can be more easily understood. System **200** also can be used to reverse engineer multiple existing procedures/scripts (even written in different languages) to a single formal model by which the procedures/scripts are combined, analyzed for conflicts, and regenerated as a single procedure/script (in the same or a different procedure/scripting language).

Some embodiments of system **200** may operate in a multi-processing, multi-threaded operating environment on a computer, such as the computer **1702** illustrated in FIG. **17**. While the system **200** is not limited to any particular scenarios **202**, inference engine **204**, translator **206**, formal specification **208**, analyzer **210**, script translator **212** and script **214**, for sake of clarity, embodiments of simplified scenarios **202**, inference engine **204**, translator **206**, formal specification **208**, analyzer **210**, script translator **212** and script **214** are described.

In some embodiments, the system **200** may be a software development system that can include a data flow and processing points for the data. System **200** can be representative of (i) computer applications and electrical engineering applications such as chip design and other electrical circuit design, (ii) business management applications in areas such as workflow analysis, (iii) artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, (iv) highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, and (v) any other area involving process, sequence or algorithm design. One skilled in the art, however, will recognize that other applications can exist that are within the purview of this invention. According to the disclosed embodiments, system **200** can, without human intervention, convert different types of specifications (such as natural language scenarios or descriptions which are effectively pre-processed scenarios) into process-based scripts on which model checking and other mathematics-based verifications are performed, and then optionally convert the script into code.

System **200** can be operational for a wide variety of languages for expressing requirements, thus system **200** may be generally applicable. Such applications may include, without limitation, distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, chemical plant operation and control, and autonomous systems. One skilled in the art will understand that these applications are cited by way of example and that other applications can fall within the scope of the invention.

According to some embodiments, a scenario can be a natural language text (or a combination of any, such as possibly graphical, representations of sequential steps or events) that describes the software's actions in response to incoming data and the internal goals of the software. Scenarios also can describe communication protocols between systems and between the components within the systems. Scenarios also can be known as use cases. A scenario can describe one or more potential executions of a system, such as describing what happens in a particular situation and what range of behaviors is expected from or omitted by the system under various conditions.

Natural language scenarios can be constructed in terms of individual scenarios written in a structured natural language. Different scenarios can be written by different stakeholders of the system, corresponding to the different views the stakeholders can have of how the system will perform, including alternative views corresponding to higher or lower levels of abstraction. Natural language scenarios can be generated by a user with or without mechanical or computer aid. Such a set of natural language scenarios can provide the descriptions of actions that occur as the software executes. Some of these actions can be explicit and required, while others can be due to errors arising or as a result of adapting to changing conditions as the system executes.

For example, if the system involves commanding space satellites, scenarios for that system can include sending commands to the satellites and processing data received in response to the commands. Natural language scenarios may be specific to the technology or application domain to which the natural language scenarios are applied. A fully automated general purpose approach covering all domains can be technically prohibitive to implement in a way that is both complete and consistent.

To ensure consistency, the domain of application can often be purpose-specific. For example, scenarios for satellite systems may not be applicable as scenarios for systems that manufacture agricultural chemicals.

FIG. **3** is a block diagram that provides an overview of a system **300** to generate a high-level computer source code program from an informal specification, according to an embodiment that includes a pattern matcher. System **300** may solve the need in the art for an automated, generally applicable way to produce a system that is a provably correct implementation of an informal design specification that does not require, in applying the system to any particular problem or application, the use of a theorem-prover. In some embodiments, system **300** requires less computing resources and time than required in using a theorem-prover, while still affording the benefits of using a theorem-prover such as reduced amount of testing required of a new system, and improved confidence that the systems reflects the requirements.

In some embodiments, system **300** is a software development system that includes a data flow and processing points for the data. System **300** can be representative of (i) computer applications and electrical engineering applications such as chip design and other electrical circuit design (ii) business management applications in areas such as workflow analysis, (iii) artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, (iv) highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, (v) remote space vehicles such as autonomous nanotechnology swarm (ANTS) and moon and Mars exploration vehicles, (vi) recognition of protein sequences in DNA samples, identifying rogue agents in a software system, and identification of viruses or other malicious code in software systems and (vii) any other area involving process, sequence or algorithm design. According to the disclosed embodiments, system **300** can mechanically convert different types of specifications (either natural language scenarios or descriptions which are effectively pre-processed scenarios) into process-based formal specifications on which model checking and other mathematics-based verifications are performed, and then optionally convert the formal specification into code.

In some embodiments, system **300** includes an informal specification **102** having a plurality of rules or requirements. The informal specification **102** can be expressed in restricted natural language, graphical notations, English language, programming language representations, scenarios, or even using semi-formal notations such as unified modeling language (UML) use cases.

System **300** may also include a set of laws of concurrency **104**. The informal specification **102** and a set of laws of concurrency **104** can be received by a mechanical pattern matcher **302**. The plurality of rules or requirements of the informal specification **102** may be pattern-matched mechanically to a process-based specification **108** or other formal specification language representation. In some embodiments, the mechanical aspect means that no manual intervention in the translation is provided. In some embodiments, the process-based specification **108** is an intermediate notation or language of process algebra such as Hoare's language of Communicating Sequential Processes (CSP).

According to some embodiments, the pattern matcher **302** matches patterns of traces against the traces that would be generated by each of the laws of concurrency **104**. The traces can be simplified versions of the scenarios. The traces generated by each law of concurrency **104** may be specified as a set in comprehension; that is, instead of listing all of the traces that a law would generate, a rule for generating this set is provided. A trace, or traces, can now be pattern matched against a set of traces generated by a law by comparing the trace(s) to the rule and seeing if it is admitted by the rule. A trace can match more than one rule, in which case the choice may be arbitrary (possibly resulting in an inefficient result, but this can be optimized later), or a trace can be based on some knowledge of the domain that can be encoded in a tool to perform the pattern matching.

The process-based specification **108** may be mathematically and provably equivalent to the informal specification **102**. Mathematically equivalent does not necessarily mean mathematically equal. Mathematical equivalence of A and B means that A implies B and B implies A. Note that applying the laws of concurrency **104** to the process-based specification **108** might allow for the retrieval of a trace-based specification that is equivalent to the informal specification **102**. Also, note that the process-based specification **108** may be mathematically equivalent to rather than necessarily equal to the original informal specification **102**. This aspect may indicate that the process may be reversed, allowing for reverse engineering of existing systems, or for iterative development of more complex systems.

In some embodiments, the system includes an analyzer **110** to determine various properties such as existence of omissions, deadlock, livelock, and race conditions in the process-based specification **108**.

System **300** may also includes a code translator **112** to translate the plurality of process-based specification segments **108** to a set of instructions in a high-level computer language program **114**, such as the Java language.

In some embodiments, system **300** is operational for a wide variety of informal specification languages and applications, thus system **300** can be generally applicable. Such applications may include distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, chemical plant operation and control, and autonomous systems.

System **300** may provide mechanical regeneration of the executable system when requirements dictate a change in the high level specification. In some embodiments of system **300**, all that is required to update the generated application is a change in the informal specification **102**, and then the changes and validation can ripple through in a mechanical process when system **300** operates. This may also allow the possibility of cost effectively developing competing designs for a product and implementing each to determine the best one. Thus, system **300** can reduce system development time, reduce the amount of testing required of a new system, and improve confidence that the system reflects the requirements.

In some embodiments, system **300** does not include a theorem-prover to infer the process-based specification segments from the informal specification. However, the plurality of process-based specification segments **108** can be provably correct implementations of the informal specification **102**, provided the developer of an instance of system **300** has properly used a theorem-prover (not shown) to prove that the mechanical pattern matcher **302** correctly translates informal specifications into formal specifications.

Some embodiments of system **300** operate in a multi-processing, multi-threaded operating environment on a computer, such as computer **1702** in FIG. **17**. While the system **300** may not be limited to any particular informal specification **102**, plurality of rules or requirements, set of laws of concurrency **104**, mechanical pattern matcher **302**, process-based specification **108**, analyzer **110**, code translator **112** and high-level computer language program **114**, for sake of clarity a simplified informal specification **102**, plurality of rules or requirements, set of laws of concurrency **104**, pattern matcher **302**, process-based specification **108**, analyzer **110**, code translator **112**, and high-level computer language program **114** are described.

In some embodiments, system **300** relates to the fields of chemical or biological process design or mechanical system design, and, generally to any field where the behaviors exhibited by a process to be designed is described by a set of scenarios expressed in natural language, or some appropriate graphical notation or textual notation.

FIG. **4** is a block diagram that provides an overview of a system **400** to engineer an implementation from scenarios, according to an embodiment. System **400** may reduce system development time, reduce the amount of testing required of a new system, and improve confidence that the system reflects the requirements.

At least one embodiment of the system **400** is a software development system that includes a data flow and processing points for the data. According to the disclosed embodiments, system **400** can convert scenarios into an implementation on which model checking and other mathematics-based verifications can then be performed.

The system **400** can include a plurality of scenarios **202**. The scenarios **202** can be written in a particular syntax, such as constrained natural language or graphical representations. The scenarios **202** can embody software applications, although one skilled in the art will recognize that other applications fall within the purview of this invention.

In at least one embodiment, the scenarios **202** are received by a pattern matcher **402**. The optional inference engine **204** might be referenced by the pattern matcher **402** when the scenarios **202** are translated by the pattern matcher **402** into a formal specification **404**. Subsequently, the formal specification **404** can be translated by a translator **408** into an implementation **410** in some appropriate scripting language or other implementation language. In some embodiments, no manual intervention in the translation is provided; thus, system **400** can improve confidence that the system reflects the requirements, which in turn can reduce the amount of testing required of a new system and reduce system development time. Those skilled in the art will readily understand that other appropriate notations and/or languages exist that are within the scope of this invention.

In some embodiments, system **400** can include an analyzer **406** to determine various properties of the formal specification, such as the existence of omissions, deadlock, livelock, and race conditions, as well as other conditions, in the formal specification **404**, although one skilled in the art will recognize that other additional properties can be determined by the analyzer **406**. The analyzer **406** may solve the need in the prior art to reduce errors.

In some embodiments, the implementation **410** can be mathematically and provably equivalent to the scenarios **202**. Mathematically equivalent does not necessarily mean mathematically equal. Mathematical equivalence of A and B means that A implies B and B implies A. Note that the implementation **410** of some embodiments can be mathematically equivalent to, rather than necessarily equal to, the scenarios **202**.

In some embodiments, the formal specification **404** can be a process-based specification, such as process algebra encoded notation. The process algebra encoded notation can be a mathematically notated form. This embodiment may satisfy the need in the art for an automated, mathematics-based process for requirements validation that does not require large computational facilities.

In some embodiments, the scenarios **202** of system **400** can specify allowed situations, events and/or results of a software system. In that sense, the scenarios **202** can provide a very abstract specification of the software system.

Some embodiments of system **400** can be operational for a wide variety of rules, computer instructions, computer languages and applications; thus, system **400** can be generally applicable. Such applications can include, without limitation, space satellite control systems, distributed software systems, sensor networks, robot operations, complex scripts for spacecraft integration and testing, chemical plant operation and control, autonomous systems, electrical engineering applications such as chip design and other electrical circuit design, business management applications in areas such as workflow analysis, artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, and any other area involving process, sequence or algorithm design. Hence, one skilled in the art will recognize that any number of other applications not listed can fall within the scope of this invention.

Some embodiments of the system **400** can provide mechanical or automatic generation of the implementation **410**, in which human intervention is not required. In at least one embodiment of the system **400**, all that may be required to update the generated application is a change in the scenarios **202**, in which case the changes and validation can ripple through the entire system without human intervention when system **400** operates. This also allows the possibility of cost effectively developing competing designs for a product and implementing each to determine the best one.

Some embodiments of the system **400** do not include an automated logic engine, such as a theorem-prover or an automated deduction engine, to infer the implementation **410** from the scenarios **202**. However, the implementation **410** can be a provably correct version of the scenarios **202**.

Thus, in regards to implementations, automatic code generation of system **400** can generate an implementation in suitable scripting language or device control language (such as for a robot) that would provide the procedures, once validated, to be automatically transformed into an implementation. Additionally, system **400** can be used to "reverse engineer" existing implementation so that the implementation can be analyzed and corrected and recast in a format and form that can be more easily understood. System **400** also can be used to reverse engineer multiple existing implementations (even written in different languages) to a single formal model by which the implementations may be combined, analyzed for conflicts, and regenerated as a single implementation (in the same or a different procedure/scripting language).

Some embodiments of system **400** operate in a multi-processing, multi-threaded operating environment on a computer, such as the computer **1702** illustrated in FIG. **17**. While the system **400** is not limited to any particular scenarios **202**, inference engine **204**, pattern matcher **402**, formal specification **404**, analyzer **406**, translator **408** and implementation **410**, for sake of clarity, embodiments of simplified scenarios **202**, inference engine **204**, pattern matcher **402**, formal specification **404**, analyzer **406**, translator **408** and an implementation **410** are described.

In some embodiments, the system **400** is a software development system that can include a data flow and processing points for the data. System **400** can be representative of (i) computer applications and electrical engineering applications such as chip design and other electrical circuit design, (ii) business management applications in areas such as workflow analysis, (iii) artificial intelligence applications in areas such as knowledge-based systems and agent-based systems, (iv) highly parallel and highly-distributed applications involving computer command and control and computer-based monitoring, and (v) any other area involving process, sequence or algorithm design. One skilled in the art, however, will recognize that other applications can exist that are within the purview of this invention. According to the disclosed embodiments, system **400** can, without human intervention, convert different types of specifications (such as natural language scenarios or descriptions which are effectively pre-processed scenarios) into a formal specification on which model checking and other mathematics-based verifications are performed, and then optionally translate the formal specification into code or some other implementation.

System **400** can be operational for a wide variety of languages for expressing requirements; thus, system **400** can be generally applicable. Such applications include, without limitation, distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, chemical plant operation and control, and autonomous systems. One skilled in the art will understand that these applications are cited by way of example and that other applications can fall within the scope of the invention.

Method Embodiments

In the previous section, a system level overview of the operation of some embodiments are described. In this section, the particular methods of some such embodiments are described by reference to a series of flowcharts. Describing the methods by reference to a flowchart enables one skilled in the art to develop such programs, firmware, or hardware, including instructions to carry out the methods on suitable computers and executing the instructions from computer-readable media. Similarly, the methods performed by the server computer programs, firmware, or hardware may also be composed of computer-executable instructions. Methods **500-1600** may be performed by a program executing on, or performed by, firmware or hardware that is a part of a computer, such as computer **1702** in FIG. **17**.

FIG. **5** is a flowchart of a method **500** to generate an executable system from an informal specification, according to an embodiment. Method **500** may solve the need in the art to generate executable computer instructions from requirements with neither the time involved in manually writing the executable computer instructions, nor the mistakes that may arise in manually writing the executable computer instructions, without using a theorem-prover.

Method **500** may include translating **502** mechanically each of a plurality of requirements of the informal specification to a plurality of process-based specification segments. In some embodiments, the translating **502** includes inferring the process-based specification segments from the informal specification. One embodiment of translating **502** is shown in FIG. **6** below.

In some embodiments, the process-based specification can be process algebra notation. Such embodiments may satisfy the need in the art for an automated, mathematics-based process for requirements validation that does not require large computational facilities.

Thereafter, method **500** may include aggregating **504** the plurality of process-based specification segments into a single process-based specification or model.

Subsequently, method **500** may include translating **506** the single process-based specification model to instructions encoded in the Java computer language or some other high-level computer programming language. Thereafter, method **500** may include compiling **508** the instructions encoded in the Java computer language or other high-level computer programming language into a file of executable instructions.

In some embodiments, method **500** includes invoking the executable instructions, which can provide a method to convert informal specifications to an application system without involvement from a computer programmer.

Some embodiments of method **500** do not include invoking a theorem-prover to infer the process-based specification segments from the informal specification.

FIG. **6** is a flowchart of a method **600** to translate mechanically each of a plurality of requirements of the informal specification to a plurality of process-based specification segments, according to an embodiment. Method **600** may include at least one embodiment of translating **502** in FIG. **5**.

According to some embodiments, method **600** includes verifying **602** the syntax of the plurality of requirements of the informal specification. Thereafter, method **600** may include mapping **604** the plurality of requirements of the informal specification to a process-based specification.

In some embodiments, method **600** subsequently also includes verifying **606** consistency of the process-based specification with at least one other process-based specification. In some embodiments, method **600** subsequently also includes verifying **608** lack of other problems in the process-based specification. One example of other problems can be unreachable states in the process defined in the process-based specification.

FIG. **7** is a flowchart of a method **700** to validate/update a system, according to an embodiment. Method **700** may solve the need in the prior art to reduce errors in scripts.

Method **700** can include analyzing **702** a script, such as script **214**, of the system **200**, the script having been previously derived from the rules of the system.

Thereafter, a determination **704** can be made as to whether or not the analyzing **702** indicates that the script contains a flaw. If a flaw does exist, then the rules can be corrected **706** accordingly.

In some embodiments, the analyzing **702** can include applying mathematical logic to the script in order to identify a presence or absence of mathematical properties of the script. Mathematical properties of the script that can be determined by applying mathematical logic to the script can include, by way of example:

1) whether or not the script implies a system execution trace that includes a deadlock condition, and

2) whether or not the script implies a system execution trace that includes a livelock condition.

The above two properties can be domain independent. One skilled in the art will note that there are many other possible flaws that could be detected through the analysis of the model, many, or even most, of which might be domain dependent. An example of a domain dependent property could be represented by the operational principle that "closing a door that is not open is not a valid action." This example could be applicable in the domain of the Hubble Space Telescope on-orbit repair.

Because in some embodiments the script can be provably equivalent to the scenarios by virtue of method **700**, if a flaw is detected in the script, then the flaw could be corrected by changing (correcting) the scenarios. Once the correction is made, then the corrected scenarios can be processed by system **200** in FIG. **2** or method **800** in FIG. **8** to derive a new script from the corrected scenarios. According to at least one embodiment, the new script can be processed by method **700**, and the iterations of method **800** and method **700** can repeat until there are no more flaws in the script generated from the scenarios, at which point the scenarios have no flaws because the script is provably equivalent to the scenarios from which it was derived. Thus, iterations of methods **800** and **700** can provide verification/validation of the scenarios.

Thereafter, the new script can be used to generate an implementation of the system.

FIG. **8** is a flowchart of a method to validate/update scenarios of a system, according to an embodiment. The method **800** can include translating **802** scenarios, such as the scenarios **202**, into a formal specification **208** without human intervention.

Thereafter, method **800** can include optionally analyzing **804** the formal model or specification **208**. The analyzing **804** can be a verification/validation of the scenarios **202**. In some embodiments, the analyzing **804** determines various properties such as existence of omissions, deadlock, livelock, and race conditions in the script **214**, although one skilled in the art will know that analyzing the formal model can determine other properties not specifically listed, which are contemplated by this invention. In some embodiments, the analyzing **804** can provide a mathematically sound analysis of the scenarios **202** in a general format that doesn't require significant understanding of the specific rules of the scenarios **202**. Further, the analyzing **804** can warn developers of errors in their scenarios **202**, such as contradictions and inconsistencies, but equally importantly it can highlight rules or sets of rules that are underspecified or over-specified and need to be corrected for the scenarios **202** to operate as intended. Thus, no knowledge of the scenarios **202** may be required, but instead significant analysis, verification, testing, simulation and model checking of the scenarios **202** using customized tools or existing tools and techniques can be provided.

Thereafter, in some embodiments, method **800** can include translating **806** the formal specification **208** to a script **214**. Thus, in at least one embodiment, the method **800** provides a method to convert scenarios to scripts without involvement from a computer programmer.

Some embodiments of the method **800** do not include invoking an automated logic engine, such as a theorem-prover, to infer the script **214** from the scenarios **202**.

In some embodiments of the method **800**, informal representations of requirements for procedures/scripts that represent the operation of a system can be mechanically converted to a mathematically sound specification that can be analyzed for defects and used for various transformations including automatic translation into executable form and automatic regeneration of procedures/scripts into other notations/representations. In other embodiments, the method disclosed herein can be used to automatically reverse engineer existing procedures and scripts to formal models from which the method can be used to produce customer-readable representations of procedures/scripts or machine-processable scripts in any of various scripting languages.

Mathematically sound techniques can be used to mechanically translate an informal procedure/script requirement into an equivalent formal model. The model may be mechanically (that is, with no manual intervention) manipulated, examined, analyzed, verified, and used in a simulation.

FIG. **9** is a flowchart of a method **900** to translate each of a plurality of requirements to a plurality of formal specification segments, and formally compose the plurality of formal specification segments into a single equivalent specification, and translate the single formal specification into a script, according to an embodiment. Method **900** may solve the need in the art to generate scripts from requirements with neither the time involved in manually writing the scripts, nor the mistakes that can arise in manually writing the scenarios, without using an automated logic engine.

Method **900** can include mechanically translating **902** each of a plurality of scenarios to a plurality of formal specification segments. The translation can be done without human intervention. One embodiment of translating **902** is shown in FIG. **10** below.

Thereafter, method **900** can include aggregating **904** the plurality of formal specification segments into a single formal specification or model.

Subsequently, method **900** can include translating **906** the single formal specification or model to multiple scripts. Thereafter, method **900** can include generating **908** a script from the scripts that were accepted from translating **906**. Thus, method **900** can provide at least one embodiment of a method to convert a script to an application system without involvement from a computer programmer.

Some embodiments of method **900** do not include invoking a theorem-prover or any other automated logic engine to infer the formal specification segments from the scenarios.

FIG. **10** is a flowchart of a method **1000** to verify the syntax of a set of scenarios, translate the set of scenarios to a formal specification, verify the consistency of the formal specification, and verify the absence of other problems, according to an embodiment. Method **1000** can be one embodiment of translating **802** in FIG. **8**. As indicated, such translation can be accomplished without human intervention.

In some embodiments, the method **1000** can include verifying **1002** the syntax of the plurality of scenarios. Thereafter, method **1000** can include mapping **1004** the plurality of scenarios to a formal specification.

In some embodiments, method **1000** subsequently can also include verifying **1006** consistency of the formal specification. In some embodiments, method **1000** subsequently also includes verifying **1008** a lack of other problems in the formal specification. One example of other problems may be unreachable states in the process defined in the formal specification, although one skilled in the art will understand that yet other problems are contemplated.

FIG. **11** is a flowchart of a method **1100** to generate an executable system from an informal specification, according to an embodiment. Method **1100** may solve the need in the art to generate executable computer instructions from requirements with neither the time nor the mistakes involved in manually writing the executable computer instructions, without using a theorem-prover.

Some embodiments of method **1100** include mechanically pattern-matching **1102** each of a plurality of scenarios of an informal specification to a plurality of process-based specification segments. In some embodiments, the pattern-matching **1102** includes inferring the process-based specification segments from the scenarios. One embodiment of pattern-matching **1102** is shown in FIG. **12** below.

In some embodiments, the process-based specification is process algebra notation. That embodiment may satisfy the need in the art for an automated, mathematics-based process for requirements validation that does not require large computational facilities.

Thereafter, some embodiments of method **1100** can include aggregating **1104** the plurality of process-based specification segments into a single process-based specification or model.

Subsequently, method **1100** may include translating **1106** the single process-based specification or model to instructions encoded in the Java computer language or some other high-level computer programming language. Thereafter, method **1100** may include compiling **1108** the instructions encoded in the high level computer programming language into a file of executable instructions or code.

In some embodiments, method **1100** includes generating the executable instructions, which can provide a method to convert informal specifications to an application system without involvement from a computer programmer.

Some embodiments of method **1100** do not include invoking a theorem-prover to infer the process-based specification segments from the informal specification.

FIG. **12** is a flowchart of a method **1200** to translate mechanically each of a plurality of requirements of the informal specification to a plurality of process-based specification segments, according to an embodiment. Method **1200** is one embodiment of pattern-matching **1102** in FIG. **11**.

Method **1200** may include verifying **1202** the syntax of the plurality of informal requirements of the specification. Thereafter, method **1200** may include mapping **1204** the plurality of informal requirements of the specification to a process-based specification.

In some embodiments, method **1200** subsequently also includes verifying **1206** consistency of the process-based specification with at least one other process-based specification. In some embodiments, method **1200** subsequently also includes verifying **1208** a lack of other problems in the process-based specification. One example of other problems might include unreachable states in the process defined in the process-based specification.

FIG. **13** is a flowchart of a method **1300** to validate/update a system, according to an embodiment. Method **1300** may solve the need in the prior art to reduce errors in specifications.

Method **1300** can include analyzing **1302** a specification, such as formal specification **208** of the system, the specification having been previously derived from the scenarios of the system.

In some embodiments, the analyzing **1302** can include applying mathematical logic to the specification in order to identify a presence or absence of mathematical properties of the specification. Mathematical properties of the specification that can be determined by applying mathematical logic to the specification can include, by way of example:

1) whether or not the specification implies a system execution trace that includes a deadlock condition, and

2) whether or not the specification implies a system execution trace that includes a livelock condition.

The above two properties can be domain independent. One skilled in the art will note that there are many other possible flaws that could be detected through the analysis of the model, many or even most of which might be domain dependent. An example of a domain dependent property would be represented by the operational principle that "closing a door that is not open is not a valid action." This example could be applicable in the domain of the Hubble Space Telescope on-orbit repair.

Because in some embodiments the specification can be provably equivalent to the scenarios by virtue of method **1300**, if a flaw is detected in the specification, then the flaw could be corrected by changing (correcting) the scenarios. Once the correction is made, then the corrected scenarios can be processed by system **200** in FIG. **2** or method **1400** in FIG. **14** to derive a new specification from the corrected scenarios. According to at least one embodiment, the new specification can be processed by method **1300**, and the iterations of method **1400** and method **1300** can repeat until there are no more flaws in the specification generated from the scenarios, at which point the scenarios have no flaws because the specification can be provably equivalent to the scenarios from which it was derived. Thus, iterations of methods **1400** and **1300** can provide verification/validation of the scenarios.

Thereafter, a determination **1304** can be made as to whether or not the analyzing **1302** indicates that the specification contains a flaw. If a flaw does exist, then the rules/scenarios/requirements can be corrected **1306** accordingly.

Thereafter, the new specification can be used to generate an implementation of the system.

FIG. **14** is a flowchart of a method to pattern-match scenarios into a formal specification, analyze the formal specification, and translate the formal specification into an implementation, according to an embodiment.

Method **1400** can include pattern-matching **1402** scenarios, such as scenarios **202**, into a formal model or specification without human intervention. Thereafter, method **1400** can include analyzing **1404** the formal specification or model. The analyzing **1404** can be a verification/validation of the scenarios **202**. In some embodiments, the analyzing **1404** determines various properties such as existence of omissions, deadlock, livelock, and race conditions in the formal specification, although one skilled in the art will know that analyzing the formal model can determine other properties not specifically listed, which are contemplated in method **1400**. In some embodiments, the analyzing **1404** can provide a mathematically sound analysis of the scenarios **202** in a general format that doesn't require significant understanding of the specific rules of the scenarios **202**. Further, the analyzing **1404** can warn developers of errors in their scenarios **202**, such as contradictions and inconsistencies, but equally importantly, it can highlight rules or sets of rules that are underspecified or over-specified and need to be corrected for the scenarios **202** to operate as intended. Thus, in some embodiments, no knowledge of the scenarios **202** is required, but instead significant analysis, verification, testing, simulation and model checking of the scenarios **202** using customized tools or existing tools and techniques is provided.

Thereafter, in some embodiments, method **1400** can include translating **1406** the formal specification into an implementation, such as implementation **214**. Thus, in at least one embodiment, the method **1400** provides a method to convert scenarios to implementations without involvement from a computer programmer.

Some embodiments of the method **1400** do not include invoking an automated logic engine, such as a theorem-prover, to infer the implementation **214** from the scenarios **202**.

In method **1400**, informal representations of requirements for implementations that represent the operation of a system can be mechanically converted to a mathematically sound specification that can be analyzed for defects and used for various transformations, including automatic translation into executable form and automatic regeneration of implementations into other notations/representations. In some embodiments, the method disclosed herein can be used to automatically reverse engineer existing implementations to formal models or specifications from which the method can be used to produce customer-readable representations of implementations or machine-processable implementations in any of various languages.

Mathematically sound techniques can be used to mechanically translate an informal scenario requirement into an equivalent formal specification or model. The model may be mechanically (that is, with no manual intervention) manipulated, examined, analyzed, verified, and used in a simulation.

FIG. **15** is a flowchart of a method **1500** to translate each of a plurality of requirements to a plurality of formal specification segments, and formally compose the plurality of formal specification segments into a single equivalent specification, according to an embodiment. Method **1500** can solve the need in the art to generate scenarios from requirements with neither the time involved nor the mistakes that can arise in manually writing the scenarios, without using an automated logic engine.

Method **1500** can include mechanically pattern-matching **1502** domain knowledge to a plurality of formal specification segments. The translation can be done without human intervention. One embodiment of pattern-matching **1502** is shown in FIG. **16** below.

Thereafter, method **1500** can include aggregating **1504** the plurality of formal specification segments into a single formal specification or model.

Some embodiments of method **1500** do not include invoking a theorem-prover or any other automated logic engine to infer the implementation from the domain knowledge.

FIG. **16** is a flowchart of a method **1600** to verify the syntax of a set of domain knowledge, translate the set of domain knowledge to a formal specification, verify the consistency of the formal specification, and verify the absence of other problems, according to an embodiment. Method **1600** can be one embodiment of pattern-matching **1502** in FIG. **15**. As indicated, such translation can be accomplished without human intervention.

In some embodiments, the method **1600** can include verifying **1602** the syntax of the domain knowledge. Thereafter, method **1600** can include mapping **1604** the set of domain knowledge to a formal specification.

In some embodiments, method **1600** subsequently can also include verifying **1606** consistency of the formal specification segment. In some embodiments, method **1600** also subsequently includes verifying **1608** a lack of other problems in the formal specification. One example of other problems can be unreachable states in the process defined in the formal specification, although one skilled in the art will understand that yet other problems are contemplated.

In some embodiments, methods **500**-**1600** can be implemented as a computer data signal embodied in a carrier wave that represents a sequence of instructions, which, when executed by a processor, such as processor **1704** in FIG. **17**, cause the processor to perform the respective method. In other embodiments, methods **500**-**1600** can be implemented as a computer-accessible medium having executable instructions capable of directing a processor, such as processor **1704** in FIG. **17**, to perform the respective method. In varying embodiments, the medium can be a magnetic medium, an electronic medium, an electromagnetic medium, a medium involving configurations or spatial positioning of electrons, ions, atoms, or molecules or aggregations of such particles, a medium involving quantum mechanical entities, or an optical medium. Other mediums will be readily apparent to one skilled in the art and fall within the scope of this invention.

Hardware and Operating Environment

FIG. **17** is a block diagram of the hardware and operating environment **1700** in which different embodiments can be practiced. The description of FIG. **17** provides an overview of computer hardware and a suitable computing environment in conjunction with which some embodiments can be implemented. Embodiments are described in terms of a computer executing computer-executable instructions. However, some embodiments can be implemented entirely in computer hardware in which the computer-executable instructions are implemented in read-only memory. Some embodiments can also be implemented in client/server computing environments where remote devices that perform tasks are linked through a communications network. Program modules can be located in both local and remote memory storage devices in a distributed computing environment. Some embodiments can also be at least partially implemented in a quantum mechanical computing and communications environment.

Computer **1702** may include a processor **1704**, commercially available from Intel, Motorola, Cyrix and others. Computer **1702** may also include random-access memory (RAM) **1706**, read-only memory (ROM) **1708**, and one or more mass storage devices **1710**, and a system bus **1712**, that operatively couples various system components to the processing unit **1704**. The memory **1706**, **1708**, and mass storage devices, **1710**, are types of computer-accessible media. Mass storage devices **1710** are more specifically types of nonvolatile computer-accessible media and can include one or more hard disk drives, floppy disk drives, optical disk drives, and tape cartridge drives. The processor **1704** can execute computer programs stored on the computer-accessible media.

Computer **1702** can be communicatively connected to the Internet **1714** (or any communications network) via a communication device **1716**. Internet **1714** connectivity is well known within the art. In one embodiment, a communication device **1716** may be a modem that responds to communication drivers to connect to the Internet via what is known in the art as a "dial-up connection." In another embodiment, a communication device **1716** may be an Ethernet® or similar hardware network card connected to a local-area network (LAN) that itself is connected to the Internet via what is known in the art as a "direct connection" (e.g., TI line, etc.).

A user may enter commands and information into the computer **1702** through input devices such as a keyboard **1718** or a pointing device **1720**. The keyboard **1718** can permit entry of textual information into computer **1702**, as known within the art, and embodiments are not limited to any particular type of keyboard. Pointing device **1720** can permit the control of the screen pointer provided by a graphical user interface (GUI) of operating systems such as versions of Microsoft Windows®. Embodiments are not limited to any particular pointing device **1720**. Such pointing devices may include mice, touch pads, trackballs, remote controls and point sticks. Other input devices (not shown) can include a microphone, joystick, game pad, gesture-recognition or expression recognition devices, or the like.

In some embodiments, computer **1702** may be operatively coupled to a display device **1722**. Display device **1722** can be connected to the system bus **1712**. Display device **1722** can permit the display of information, including computer, video and other information, for viewing by a user of the computer. Embodiments are not limited to any particular display device **1722**. Such display devices may include cathode ray tube

(CRT) displays (monitors), as well as flat panel displays such as liquid crystal displays (LCD's) or image and/or text projection systems or even holographic image generation devices. In addition to a monitor, computers typically may include other peripheral input/output devices such as printers (not shown). Speakers **1724** and **1726** (or other audio device) can provide audio output of signals. Speakers **1724** and **1726** can also be connected to the system bus **1712**.

Computer **1702** may also include an operating system (not shown) that may be stored on the computer-accessible media RAM **1706**, ROM **1708**, and mass storage device **1710**, and can be executed by the processor **1704**. Examples of operating systems include Microsoft Windows®, Apple MacOS®, Linux®, UNIX®. Examples are not limited to any particular operating system, however, and the construction and use of such operating systems are well known within the art.

Embodiments of computer **1702** are not limited to any type of computer **1702**. In varying embodiments, computer **1702** may comprise a PC-compatible computer, a MacOS®-compatible computer, a Linux®-compatible computer, or a UNIX®-compatible computer. The construction and operation of such computers are well known within the art.

Computer **1702** can be operated using at least one operating system to provide a graphical user interface (GUI) including a user-controllable pointer. Computer **1702** can have at least one web browser application program executing within at least one operating system, to permit users of computer **1702** to access an intranet, extranet or Internet world-wide-web pages as addressed by Universal Resource Locator (URL) addresses. Examples of browser application programs include Netscape Navigator® and Microsoft Internet Explorer®.

The computer **1702** can operate in a networked environment using logical connections to one or more remote computers, such as remote computer **1728**. These logical connections can be achieved by a communication device coupled to, or a part of, the computer **1702**. Embodiments are not limited to a particular type of communications device. The remote computer **1728** can be another computer, a server, a router, a network PC, a client, a peer device or other common network node. The logical connections depicted in FIG. **17** include a local-area network (LAN) **1730** and a wide-area network (WAN) **1732**. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets, extranets and the Internet.

When used in a LAN-networking environment, the computer **1702** and remote computer **1728** can be connected to the local network **1730** through network interfaces or adapters **1734**, which is one type of communications device **1716**. Remote computer **1728** may also include a network device **1736**. When used in a conventional WAN-networking environment, the computer **1702** and remote computer **1728** may communicate with a WAN **1732** through modems (not shown). The modem, which can be internal or external, may be connected to the system bus **1712**. In a networked environment, program modules depicted relative to the computer **1702**, or portions thereof, can be stored in the remote computer **1728**.

Computer **1702** also includes power supply **1738**. Each power supply can be a battery.

Apparatus Embodiments

CSP Implementation

Referring to FIG. **18**, a particular CSP implementation **1800** is described in conjunction with the system overview in FIG. **1** and the methods described in conjunction with FIG. **3** and FIG. **6**, according to an embodiment.

FIG. **18** is a block diagram of a particular CSP implementation of an apparatus **1800** to generate a high-level computer source code program from an informal specification, according to an embodiment. Apparatus **1800** may solve the need in the art for an automated, generally applicable way to produce a system that is a provably correct implementation of an informal design specification that does not require use of a theorem-prover.

Apparatus **1800** may include an informal specification **102** having a plurality of rules or requirements. The informal specification **102** can be expressed in restricted natural language, graphical notations, or even using semi-formal notations such as unified modeling language (UML) use cases. Apparatus **1800** may also include a set of laws of concurrency **104**.

The informal specification **102** and a set of laws of concurrency **104** may be received by a mechanical CSP translator **1802**. The plurality of rules or requirements of the informal specification **102** can be translated mechanically to a CSP specification **1804** encoded in Hoare's language of Communicating Sequential Processes (CSP). In some embodiments, the mechanical CSP translator **1802** performs action **302** in FIG. **3**.

In some embodiments, the system may include a formal specification analyzer **1806** to perform model verification/checking and determine existence of omissions, deadlock, livelock and race conditions in the CSP specification **1804**. In some embodiments, the formal specification analyzer **1806** receives and transmits information from and to a visualization tool **1808** that can provide a way to modify the CSP specification **1804**. In some embodiments, the formal specification analyzer **1806** receives and transmits information from and to a tool **1810** designed for CSP that provides a way to modify the CSP specification **1804**.

The formal specification analyzer **1806** may generate a modified CSP specification **1812** that may in turn be received by a code translator or compiler **112** to translate the modified CSP specification **1808** to a set of instructions in a high-level computer language program **114**, such as Java language.

CSP specification analyzer **1806** may allow the user to manipulate the CSP specification **1804** in various ways. The analyzer **1806** may allow the user to examine the system described by the informal specification **102**, and to manipulate it. The CSP specification **1804** may be analyzed to highlight undesirable behavior, such as race conditions, and equally important, to point out errors of omission in the informal specification **102**. The CSP specification analyzer **1806** can be an optional but useful stage in the disclosed embodiments of the present invention. If the analyzer **1806** is not used, then the process-based specification **108** and the modified CSP specification **1804** may be identical. Hence, if the CSP analyzer **1806** is not used, then all references to the modified CSP specification **1812** disclosed below may also apply to the CSP specification **1804**.

Some embodiments of apparatus **1800** do not include a theorem-prover to infer the process-based specification segments from the informal specification.

Apparatus **1800** can be operational for a wide variety of informal specification languages and applications, and thus apparatus **1800** may be generally applicable. Such applications may include distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, and autonomous systems.

Apparatus **1800** components of the mechanical CSP translator **1802**, the formal specification analyzer **1806**, visualization tool **1808**, CSP tool **1810** and the code translator **112** can be embodied as computer hardware circuitry or as a computer-readable program, or a combination of both, such as shown in FIG. **18**. In another embodiment, apparatus **1800** can be implemented in an application service provider (ASP) system.

FIG. **19** is a block diagram of a hardware and operating environment in which a particular CSP implementation of FIG. **18** may be implemented, according to an embodiment.

Script Implementation

Referring to FIGS. **20** and **21**, a particular scripting language implementation **2000** is described in conjunction with the system overview in FIG. **2** and the methods described in conjunction with FIGS. **5-16**.

FIG. **20** is a block diagram of a particular implementation of an apparatus capable of translating scenarios to a formal specification, optionally analyzing the formal specification and translating the formal specification to a script and reverse engineering (translating) a script into a formal specification (and possibly analyzing the formal specification), according to an embodiment. Apparatus **2000** may solve the need in the art for an automated, generally applicable way to verify that implemented scripts are a provably correct implementation of a scenario(s).

Apparatus **2000** can include a translator **206** that generates a formal specification **208** from the laws of concurrency **104** and the scenario(s) **202** in reference to the optional inference engine **204**.

Subsequently, the formal specification **208** may be translated by a script translator **212** into a script **214** in some appropriate scripting language. In some embodiments, no manual intervention in the translation may be provided. Those skilled in the art will readily understand that other appropriate notations and/or languages exist that are within the scope of this invention.

In some embodiments, apparatus **2000** can include an analyzer **210** to determine various properties of the formal specification, such as the existence of omissions, deadlock, livelock, and race conditions, as well as other conditions, in the formal specification **208**, although one skilled in the art will recognize that other additional properties can be determined by the analyzer **210**. The analyzer **210** may solve the need in the prior art to reduce errors.

In some embodiments, a reverse script translator **2002** receives the script **214** and generates a formal specification **208**. In various embodiments, the output of the reverse script translator **2002** is a different formal specification than formal specification **208** received from translator **206**. While there can be some small differences between the formal specification generated by reverse script translator **2002** and formal specification **208**, the formal specifications generated by the reverse script translator **2002** can be substantially functionally equivalent to the formal specification **208**.

Apparatus **2000** can operate for a wide variety of languages and applications, and thus apparatus **2000** may be generally applicable. Such applications can include, without limitation, distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, and autonomous systems, but those skilled in the art will understand that other applications are contemplated.

Apparatus **2000** components such as the translator **206**, script translator **212**, the script analyzer **210**, and the reverse script translator **2002** can be embodied as computer hardware circuitry or as a computer-readable program, or a combination of both, such as shown in FIG. **21**. In another embodiment, apparatus **2000** can be implemented in an application service provider (ASP) system.

FIG. **21** illustrates an environment **2100** similar to that of FIG. **17**, but with the addition of the script translator **212**, the analyzer **210** and the reverse script translator **2002** that correspond to some of apparatus **2000**, according to an embodiment.

In a computer-readable program embodiment, the programs can be structured in an object-orientation using an object-oriented language such as Java, Smalltalk or C++, and the programs can be structured in a procedural-orientation using a procedural language such as COBOL or C. The software components may communicate in any of a number of ways that are well-known to those skilled in the art, such as application program interfaces (API) or interprocess communication techniques such as remote procedure call (RPC), common object request broker architecture (CORBA), Component Object Model (COM), Distributed Component Object Model (DCOM), Distributed System Object Model (DSOM) and Remote Method Invocation (RMI). The components can execute on as few as one computer as in computer **1702** in FIG. **17**, or on at least as many computers as there are components.

Referring to FIG. **22**, a particular apparatus **2200** is described in conjunction with the system overview in FIG. **1** and the methods described in conjunction with FIG. **11** and FIG. **12**, according to an embodiment.

FIG. **22** is a block diagram of a particular embodiment of an apparatus **2200** to generate a high-level computer source code program from an informal specification. Apparatus **2200** may solve the need in the art for an automated, generally applicable way to produce a system that is a provably correct implementation of an informal design specification that does not require use of a theorem-prover.

Apparatus **2200** may include an informal specification **102** having a plurality of rules or requirements. The informal specification **102** can be expressed in restricted natural language, graphical notations, or even using semi-formal notations such as unified modeling language (UML) use cases. Apparatus **2200** may also include a set of laws of concurrency **104**.

In some embodiments, the informal specification **102** and a set of laws of concurrency **104** are received by a mechanical implementation pattern matcher **2202**. The plurality of rules or requirements of the informal specification **102** can be translated mechanically to an implementation **2204**. In some embodiments, the mechanical implementation pattern matcher **2202** performs actions **1102** and **1104** in FIG. **11**.

In some embodiments, the system includes an implementation analyzer **2206** to perform model verification/checking and determine existence of omissions, deadlock, livelock and race conditions in the implementation **2204**. In some embodiments, the implementation analyzer **2206** receives and transmits information from and to a visualization tool **2208** that provides a way to modify the implementation **2204**. In some embodiments, the implementation analyzer **2206** receives and transmits information from and to a tool **2210** that provides a way to modify the implementation **2204**.

The implementation analyzer **2206** can generate a modified implementation **2212** that is in turn received by a code translator **112** or compiler to translate the modified implementation **2212** to a set of instructions in a high-level computer language program **114**, such as Java language.

The implementation analyzer **2206** may allow the user to manipulate the implementation **2204** in various ways. The implementation analyzer **2206** can allow the user to examine the system described by the informal specification **102**, and to manipulate it. The implementation **2204** may be analyzed to highlight undesirable behavior, such as race conditions, and equally important, to point out errors of omission in the informal specification **102**. The implementation analyzer **2206** can be an optional but useful stage in the disclosed embodiments of the present invention. If the implementation analyzer **2206** is not used, then the implementation **2204** and the modified implementation **2212** are identical. Hence, if the implementation analyzer **2206** is not used then all references to the modified implementation **2212** disclosed below may also apply to the implementation **2204**.

In some embodiments, apparatus **2200** does not include a theorem-prover to infer the process-based specification segments from the informal specification.

Apparatus **2200** can be operational for a wide variety of informal specification languages and applications; thus apparatus **2200** can be generally applicable. Such applications may include distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, and autonomous systems.

Apparatus **2200** components of the mechanical implementation pattern matcher **2202**, the implementation analyzer **2206**, visualization tool **2208**, tool **2210** and the code translator **112** can be embodied as computer hardware circuitry or as a computer-readable program, or a combination of both, such as shown in FIG. **23**. In another embodiment, apparatus **2200** is implemented in an application service provider (ASP) system.

FIG. **23** is a block diagram of a hardware and operating environment in which a particular pattern-matching implementation of FIG. **22** is implemented, according to an embodiment.

Referring to FIGS. **24** and **25**, a particular pattern-matching embodiment **2400** is described in conjunction with the system overview in FIG. **2** and the methods described in conjunction with FIGS. **5-16**.

FIG. **24** is a block diagram of a particular embodiment of an apparatus capable to pattern-match scenarios to a formal specification, optionally analyze the formal specification and translate the formal specification to an implementation and reverse engineer (translate) the implementation into a formal specification (and possibly analyze the formal specification), according to an embodiment. Apparatus **2400** can solve the need in the art for an automated, generally applicable way to verify that implemented scenarios and other implementations are a provably correct implementation of a scenario(s).

Apparatus **2400** can include a pattern matcher **206** that generates a formal specification **208** from the laws of concurrency **104** and the scenario(s) **202** in reference to the optional inference engine **204**.

Subsequently, the formal specification **208** may be translated by translator **408** into an implementation **410**. In some embodiments no manual intervention in the translation is provided. Those skilled in the art will readily understand that other appropriate notations and/or languages exist that are within the scope of apparatus **2400**.

In some embodiments, apparatus **2400** can include an analyzer **406** to determine various properties of the formal specification, such as the existence of omissions, deadlock, livelock, and race conditions, as well as other conditions, in the formal specification **208**, although one skilled in the art will recognize that other additional properties can be determined by the analyzer **406**. The analyzer **406** may solve the need in the prior art to reduce errors.

In some embodiments, a reverse translator **2402** receives the implementation **410** and generates a formal specification **208**. The output of the reverse translator **2402** can be a different formal specification than formal specification **208**. There can be some small differences between the formal specification generated by reverse translator **2402** and formal specification **208**, but the formal specifications generated by the reverse translator **2402** can be substantially functionally equivalent to the formal specification **208**.

Apparatus **2400** can operate for a wide variety of languages and applications, and thus apparatus **2400** can be generally applicable. Such applications can include, without limitation, distributed software systems, sensor networks, robot operation, complex scripts for spacecraft integration and testing, and autonomous systems, but those skilled in the art will understand that other applications are contemplated.

Apparatus **2400** components such as the pattern matcher **206**, translator **408**, the analyzer **406**, and the reverse translator **2402** can be embodied as computer hardware circuitry or as a computer-readable program, or a combination of both, such as shown in FIG. **25**. In another embodiment, apparatus **2400** can be implemented in an application service provider (ASP) system.

FIG. **25** illustrates an environment **2500** similar to that of FIG. **17**, according to an embodiment, but with the addition of the translator **408**, the analyzer **406** and the reverse translator **2402** that correspond to some of apparatus **2400**.

CONCLUSION

Systems, methods and apparatus described herein may have many commercial applications, such as (1) Business procedures, in a variety of domains, may be analyzed, evaluated, improved, combined, verified, and automatically implemented in a programming language. (2) Formal modes may have been proposed for analyzing legal contracts. However, legal experts may not be likely to have the required skills to develop such mathematical models. This approach may enable legal contracts to be converted automatically to a formal model and analyzed. (3) Procedures for assembling (or disassembling) components in a factory, in space, or elsewhere, whether performed by robots or humans, are prone to error and "trial and error." The approach disclosed herein may eliminate the uncertainty and may ensure that procedures are correct. (4) There are a large number of implementations in the public domain, in particular in communications networks and the bioinformatics industry. Similarly, NASA (and other organizations) have many existing implementations used for space mission test and integration. Most of these implementations have little or no documentation, meaning that the implementations cannot be used except by explanations of the working of the implementations, and hence their reuse. (5) Existing implementations can be combined using this approach, and can be checked for incompatibilities, etc. Then a single implementation may be generated to combine the functionality of several implementations. This may have major ramifications for bioinformatics, robotic assembly and maintenance, integration and test, and other domains.

Systems and methods for generating implementations from requirements expressed as scenarios are described according to an embodiment. In some embodiments, the systems and methods also allow for "reverse engineering," analysis, and correction of errors found in existing implementations. In some embodiments, the methods allows multiple existing implementations to be combined, discrepancies resolved and re-generated as a single implementation in which confidence can be placed in its correct implementation of the stated requirements (which can be "captured" from the existing implementation).

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose can be substituted for the specific embodiments shown. This application is intended to cover any adaptations or variations. For example, although described in procedural terms, one of ordinary skill in the art will appreciate that implementations can be made in an object-oriented design environment or any other design environment that provides the required relationships.

In some embodiments, a formal model may be generated from the scenarios. The formal model may then be analyzed for a range of different possible errors in the scenarios. Additionally, implementations can be generated that correspond to the scenarios. Since the implementations are generated automatically, there may be a significantly reduced likelihood of error, and common "programming" errors may be eliminated. These implementations may be in an implementation language such as PERL, BioPerl, PYTHON, etc. or in a language suitable for controlling machines, robots and other devices.

Existing implementations can be combined, analyzed, and regenerated as a single implementation in the same language, or another language, that increases accuracy and reduces common errors.

In particular, one of skill in the art will readily appreciate that the names of the methods and apparatus are not intended to limit embodiments. Furthermore, additional methods and apparatus can be added to the components, functions can be rearranged among the components, and new components to correspond to future enhancements and physical devices used in embodiments can be introduced without departing from the scope of embodiments. One of skill in the art will readily recognize that embodiments are applicable to future communication devices, different file systems, and new data types.

The terminology used in this application is meant to include all object-oriented, database and communication environments and alternate technologies which provide the same functionality as described herein.

We claim:

1. A non-transitory computer-accessible medium having executable instructions to validate a system, the computer-accessible medium executable instructions capable of directing a processor to perform:

receiving scenarios of the system;

pattern-matching the scenarios of the system to at least one process-based specification segment; and

analyze the formal specification,

wherein the computer executable instructions comprise pattern-matching the scenarios of the system to a formal specification, in reference to an inference engine, applying mathematical logic to the formal specification in order to identify a presence or absence of mathematical properties of the scenario, and correcting the absence of the mathematical properties if the mathematical properties are identified as absent in the scenario, and

wherein the mathematical properties of the formal specification comprise whether the formal specification implies a system execution trace that includes a deadlock condition, whether the formal specification implies a system execution trace that includes a livelock condition, and whether the formal specification implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

2. The non-transitory computer-accessible medium of claim **1**, wherein the formal specification further comprises a process algebra.

3. The non-transitory computer-accessible medium of claim **2**, wherein the process algebra comprises a language of Communicating Sequential Processes.

4. A non-transitory computer-accessible medium having executable instructions to generate a system from scenarios, the executable instructions capable of directing a processor to perform:

pattern-matching a plurality of scenarios to a formal specification; and translating the formal specification to a process-based specification implementing the system,

wherein the mathematical properties of the formal specification comprise whether the formal specification implies a system execution trace that includes a deadlock condition, whether the formal specification implies a system execution trace that includes a livelock condition, and whether the formal specification implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

5. The non-transitory computer-accessible medium of claim **4**, wherein the executable instructions further comprise:

verifying the syntax of the plurality of scenarios; and

mapping the plurality of scenarios to a plurality of formal specification segments.

6. The non-transitory computer-accessible medium of claim **4**, wherein the executable instructions further comprise:

verifying consistency of the formal specification.

7. The non-transitory computer-accessible medium of claim **4**, wherein the executable instructions further comprise:

analyzing the formal specification.

8. The non-transitory computer-accessible medium of claim **4**, wherein the executable instructions further comprise:

determining mathematical and logical properties of the formal specification by an automated inference engine.

9. The non-transitory computer-accessible medium of claim **4**, wherein the executable instructions further comprise:

pattern-matching the plurality of scenarios to a separate formal specification without the use of an automated inference engine.

10. The non-transitory computer-accessible medium of claim **4**, wherein the formal specification further comprises a process algebra.

11. The non-transitory computer-accessible medium of claim **10**, wherein the process algebra comprises a language of Communicating Sequential Processes.

12. A system to validate a software system, the system comprising:

a processor;

an inference engine;

a pattern-matcher operable to receive a plurality of scenarios of the software system and to generate in reference to the inference engine a specification encoded in a formal specification language; and

an analyzer, operable to perform model verification/checking and determine existence of omissions, deadlock, livelock, and race conditions or other problems and inconsistencies in the formal specification,

wherein the mathematical properties of the formal specification comprise whether the formal specification implies a system execution trace that includes a deadlock condition, whether the formal specification implies a system execution trace that includes a livelock condition, and whether the formal specification implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

13. The system of claim **12**, wherein the pattern-matching of the scenarios into a specification is carried out without human intervention.

14. A non-transitory computer-accessible medium having executable instructions to validate a system, the executable instructions capable of directing a processor to perform:

receiving scenarios of the system; pattern-matching the scenarios of the system to a formal specification; and

translating the formal specification to an implementation,

wherein the executable instructions further comprise analyzing the formal specification and applying mathematical logic to the formal specification in order to identify a presence or absence of mathematical properties of the formal specification, and

wherein the mathematical properties of the formal specification further comprise whether the formal specification implies a system execution trace that includes a deadlock condition, whether the formal specification implies a system execution trace that includes a livelock condition, and whether the formal specification implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

15. The non-transitory computer-accessible medium of claim **14**, wherein the executable instructions further comprise:

pattern-matching the scenarios of the system to the formal specification, without the use of an automated inference engine.

16. The non-transitory computer-accessible medium of claim **14**, wherein the executable instructions further comprise:

pattern-matching the scenarios of the system to the formal specification, in reference to an inference engine.

17. The non-transitory computer-accessible medium of claim **14**, wherein the formal specification further comprises a process algebra.

18. The non-transitory computer-accessible medium of claim **17**, wherein the process algebra comprises a language of Communicating Sequential Processes.

19. The non-transitory computer-accessible medium of claim **14**, wherein the executable instructions further comprise pattern-matching the scenario to a formal model; and translating the formal model to at least one scenario.

20. A non-transitory computer-accessible medium having executable instructions to validate a system, the executable instructions capable of directing a processor to perform:

receiving a formal model of the system; and

pattern-matching the formal model to a scenario,

wherein the executable instructions further comprise analyzing the formal model and applying mathematical logic to the formal model in order to identify a presence or absence of mathematical properties of the formal model, and

wherein the mathematical properties of the formal model comprise whether the formal model implies a system execution trace that includes a deadlock condition, whether the formal model implies a system execution trace that includes a livelock condition, and whether the formal model implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

21. The non-transitory computer-accessible medium of claim **20**, wherein the executable instructions further comprise translating the formal model to at least one scenario.

22. The non-transitory computer-accessible medium of claim **20**, wherein the formal model further comprises a process algebra.

23. The non-transitory computer-accessible medium of claim **20**, wherein the process algebra comprises a language of Communicating Sequential Processes.

24. A non-transitory computer-accessible medium having executable instructions to validate a system, the executable instructions capable of directing a processor to perform:

receiving a scenario of the system; and

pattern-matching the scenario to a formal model,

wherein the executable instructions further comprise analyzing the formal model and applying mathematical logic to the formal model in order to identify a presence or absence of mathematical properties of the formal model, and

wherein the mathematical properties of the formal model comprise whether the formal model implies a system execution trace that includes a deadlock condition, whether the formal model implies a system execution trace that includes a livelock condition, and whether the formal model implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, unexecuted code.

25. The non-transitory computer-accessible medium of claim **24**, wherein the formal model further comprises a process algebra.

26. The non-transitory computer-accessible medium of claim **25**, wherein the process algebra comprises a language of Communicating Sequential Processes.

27. A non-transitory computer-accessible medium having executable instructions to validate a system, the executable instructions capable of directing a processor to perform:

pattern-matching a plurality of scenarios to a plurality of formal models;

combining the plurality of formal models to a singular formal model;

analyzing the singular formal model;

correcting the absence of mathematical properties in the singular formal model; and

translating the formal model to an implementation,

wherein the executable instructions further comprise applying mathematical logic to the singular formal model in order to identify a presence or absence of mathematical properties of the singular formal model, and

wherein the mathematical properties of the singular formal model comprise whether the singular formal model implies a system execution trace that includes a deadlock condition, whether the singular formal model implies a system execution trace that includes a livelock condition, and whether the singular formal model implies a system execution trace that exhibits or does not exhibit a plurality of other desirable or undesirable behaviors including, but not limited to safety properties, security properties, unreachable states, inconsistencies, naming conflicts, unused variables, and unexecuted code.

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